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NATO INTERNATIONAL STAFF – DEFENCE INVESTMENT DIVISION

Miniaturised Piezo-Electric Gauges

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NORTH ATLANTIC TREATY ORGANISATION

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3. AEP-51 (Edition 1) contains only factual information. Changes to this AEP are not subject to the ratification procedures and will be promulgated on receipt from the nations concerned after endorsement by the AC/225-Land Capability Group 3 in plenary session.

J. MAJ
Major General, POL(A)
Director, NSA

NATIONAL RESERVATIONS

Nation	Specific Reservations

AMENDMENTS

No.	Reference/Date of amendment	Date entered	Signature

MANOMETRES PIEZO-ELECTRIQUES MINIATURISES	**MINIATURIZED PIEZO-ELECTRIC PRESSURE GAUGES**
1 – BESOIN Enregistrer la courbe pression-temps développée par la combustion de la poudre propulsive à l'intérieur de la chambre du canon.	***1 – NEED*** To record the pressure time curve of propellant gas in the chamber of the gun.
2 - PRINCIPE DE FONCTIONNEMENT Le bloc manométrique piézoélectrique est un capteur autonome placé dans la charge propulsive au cours de sa confection ou placé dans la chambre. Son cycle d'enregistrement est automatique dès l'apparition du phénomène à mesurer. Les caractéristiques métrologiques de ce capteur associé à sa chaîne de mesure sont ajustables au travers d'un PC avant introduction dans la munition. Après coup les mémoires sont lues sur un ordinateur pour restitution du signal enregistré.	***2 – DESCRIPTION*** The miniaturised piezo-electric gauge is an autonomous sensor put in the propelling charge during its manufacturing or put in the chamber. Recording automatically starts at the beginning of the signal. Metrological characteristics of this gauge coupled with its measuring device can be regulated through a PC before introducing ammunition. After firing, the recorded signal is stored by the computer

3 - DOMAINES D'EMPLOI :

- **3.1 - artillerie** :

3.1.1 munition encartouchée

- pression maximale attendue : 500 MPa
- volume maximum : 30 cm^3 (souhaitable : 15 cm^3)
- température d'emploi souhaitable : -46 à +65 °C

3.1.2 munition non encartouchée

- pression maximale attendue : 500 MPa ;
- volume maximum : 30 cm^3 (souhaitable : 15 cm^3)

- **3.2 - char :**

3.2.1 munition encartouchée

- pression maximale attendue : 800 MPa
- température d'emploi souhaitable : -46 à +65 °C
- volume maximum : 30 cm^3

3.2.2 munition non encartouchée

- pression maximale attendue : 800 MPa
- volume maximum : 30 cm^3

- **3.3 – mortier :**

- pression maximale attendue : 150 MPa ;
- volume (et diamètre) maximum : 10 cm^3 (Ø 1,8 cm)

3 – DIFFERENT USES :

- **3.1 - artillery :**

3.1.1 cased ammunition

- maximum pressure : 500 MPa
- maximum volume : 30 cm^3 (desirable : 15 cm^3)
- desirable operating temperature : -46 to +65 °C

3.1.2 non cased ammunition

- maximum pressure : 500 MPa
- maximum volume : 30 cm^3 (desirable : 15 cm^3)

- **3.2 - tank gun :**

3.2.1 cased ammunition

- maximum pressure : 800 MPa
- desirable operating temperature : -46 to +65 °C
- maximum volume : 30 cm^3

3.2.2 non cased ammunition

- maximum pressure : 800 MPa
- maximum volume : 30 cm^3

- **3.3 - mortar :**

- maximum pressure : 150 MPa
- maximum volume (and diameter) : 10 cm^3 (Ø 1,8 cm)

4 – EXIGENCES COMMUNES : - 1 – Incertitude sur la mesure dynamique : 2 % à 2 σ - 2 – Fréquence d'acquisition : 0,1 à 100 Khz - 3 – Durée de l'enregistrement : ≥ 80 ms - 4 – Résolution en amplitude : ≥ 12 bit - 5 – Réglage niveaux trig et pré-trig : oui - 6 – Durée de la phase « repos » : 48 h - 7 – Durée de la phase « mesure » : 3 h - 8 – Durée de la phase « récupération de données » : 1 h - 9 – Restitution des signaux : PC Windows NT (langage ASCII) - 10 – Etalonnage statique de la tête piézo dans son montage mécanique. - 11 – Mesure de la température du capteur lors de l'enregistrement. - 12 – Contrôle de la tension pile. - 13 – Réutilisation du même capteur sur des coups successifs (température maximale de réemploi à préciser par le constructeur) - 14 – Tenue aux chocs et vibrations de munitions de char (STANAG 4242) - 15 – Cycle de vie et durée de vie : à déterminer - 16 – Temperature d'emploi : 0 à 65 °C	***4 – COMMON REQUIREMENTS*** : - 1 – Uncertainty on the dynamic measurement : 2 % at 2 σ - 2 – Sampling rate : 0,1 to 100 Khz - 3 – Recording time : ≥ 80 ms - 4 – Resolution : ≥ 12 bit - 5 – Levels trigger and pre-trig : yes - 6 – Timing sequence « stand-by » : 48 h - 7 – Timing sequence « measurement » : 3 h - 8 – Timing sequence « data transfer » : 1 h - 9 – Data transfer and analysis : PC Windows NT (language ASCII) - 10 – Static calibration of piezo sensor in its mechanical housing - 11 – Temperature measurement at recording time. - 12 – Battery voltage check. - 13 – Re-use of the same gauge on several successive rounds (re-use maximum temperature will be specified by the maker) - 14 – Resistance against shock and vibration in tank ammunition (STANAG 4242) - 15 – Life cycle or life time expectancy : to be determined - 16 – Operating temperature : 0 to 65 °C

5 – PROGRAMME D'ESSAIS DE QUALIFICATION DE NOUVEAUX DISPOSITIFS	***5 –TESTS PROGRAM FOR QUALIFICATION OF NEW GAUGES***
Le programme d'essais de qualification s'applique uniquement à l'arrivée d'un nouveau type de manomètre piézoélectrique.	The qualification test program will be conducted only on the arrival of a new model of miniaturised gauge.
La décision de qualification de chaque nouveau bloc piézo-électrique sera basée sur les résultats : - des étalonnages en statique de la partie piézoélectrique; - du contrôle de l'électronique; - des contrôles dynamiques du bloc manométrique complet; - des tirs à pression maximale et aux températures extrêmes.	For each new gauge, the qualification decision will be based on the following results : - static calibration of the piezo-electric sensor; - control of electronic part; - dynamic controls of the whole gauge; - firing tests at maximum pressure and extreme temperatures.
5.1 - **Etalonnage statique de la tête piézoélectrique :** La tête piézoélectrique sera étalonnée en statique, sur toute sa gamme, suivant la procédure d'étalonnage I.T.O.P n° 3-2-810, sans son électronique.	**5.1 - Static calibration of the piezo-electric sensor :** The piezo-electric sensor will be calibrated according to the procedure ITOP 3-2-810, without the electronic part.
5.2 - **Contrôle de l'électronique :** Le procès –verbal d'étalonnage de la partie acquisition et de la partie restitution sera établi et fourni par le constructeur.	**5.2 – Control of electronic part :** The calibration report of recorded and recalled signal will be drafted and provided by the manufacturer .

5.3 - Contrôle dynamique et tenue mécanique à 65% de l'étendue de mesure:	**5.3 - Dynamic control and resistance firing test at 65% of the measuring range:**
Le manomètre subira un contrôle dynamique sur arme à un niveau de pression ≥ 65 % de son étendue de mesure.	The assembled gauge will be tested in a gun, at a pressure ≥ 65 % of the measuring range.
Les résultats enregistrés seront comparés à ceux de 2 capteurs de référence (K6215 ou K6213).	Results will be compared with those given by 2 reference sensors (K6215 or K6213)
La comparaison sera menée sur les trois critères suivants : - pression maximale; - temps de montée du signal entre 10 et 90 % de la valeur maximale de la pression ; - durée de l'impulsion de pression à 50 % de la pression maximale.	The comparison will be done according to the 3 following criteria : - maximum pressure; - rise time between 10 and 90 % of the maximum pressure; - pulse width at 50 % of the maximum pressure.
Voir annexe pour les procédures statistiques.	See annex for statistical procedures
Ces essais dynamiques porteront sur 3 blocs chacun subissant 10 coups.	These dynamic tests will be done with 3 gauges each one submitted to 10 rounds.
5.4 – Comportement du capteur à l'extrémité supérieure de l'étendue de mesure:	**5.4 – Gauge behaviour at upper extremity of the measuring range:**
Ce test est à la charge du constructeur ou de l'acheteur Il pourra être conduit en canon ou simulateur Les résultats de tir et de précision seront fournis.	This test will be assumed by the builder or the customer It can be done either in a simulator or in a gun. The firing and precision results shall be provided.

5.5 – Comportement du capteur aux températures extrêmes (- 46 °C et + 65 °C) Ce test portera sur 3 électroniques (minimum) associées à leur batterie. Description du test : - 1/ conditionnement en température de chaque ensemble pendant 48 heures ; - 2/ simulation d'un signal capteur à l'entrée de chaque électronique, enregistrement ; - 3/ contrôle du signal restitué.	**5.5 - Gauge behaviour at extreme temperatures (- 46 °C and + 65 °C)** This test will be done with 3 electronic parts (minimum) with their battery Test description : - 1/ each set will be conditioned during 48 hours ; - 2/ a sensor signal will be simulated at the input of each electronic, recording ; - 3/ control of the output signal.

6 – LISTE DES DISPOSITIFS QUALIFIES Après fourniture du rapport détaillé des essais décrits au paragraphe 6 par le pays d'origine, le SG2 décidera de l'inscription d'un nouveau type de bloc piézo-électrique, dans la liste ci-après: Fiche no 1 Constructeur: … Adresse: … Référence du bloc piéz—élecrqiue: … Longueur: … mm Diamètre: … mm Volume: … cm3 Pression maximale d'emploi validée au tir: … Mpa Liste des exigences communes satisfaites (voir para. 4): … (1 à 14) Gamme de température d'emploi testée: -… ^{o}C à …oC Références et date du rapport d'essais soumis au LG4/SG2:	***6 - LIST OF QUALIFIED GAUGES*** Any country which has tested a new gauge according to the paragraph 6, sends a report including the detailed results to SG2. Then SG2 can decide to include it as a new gauge in the following list: File no 1 Manufacturer: … Address: … Gauge reference: … Length: … mm Diameter: … mm Volume: … cm^3 Maximum validated firing pressure: … Mpa List of common requirements which have been met (para. 4 …(1 to 14)(Tested temperature range: - … ^{o}C to + … ^{o}C References and date of the test report submitted to LG/4-SG/2 ……
7- CONTROLE PERIODIQUE Périodicité : 100 coups ou 1 an. Chaque bloc subira un étalonnage statique de la tête piézoélectrique selon paragraphe 5.1.	***7 – PERIODIC CONTROL*** Periodicity : 100 rounds or 1 year. Each sensor will be submitted to a static calibration (see 5.1)

AEP 51 - Annex 1 *:*

Statistical method concerning dynamic control and mechanical resistance firing tests.

ANNEX 1
AEP-51
(Edition 1)

Miniaturised piezo-electric pressure gauge

Statistical method concerning dynamic control and mechanical resistance firing tests

1. GENERAL

Acceptance of miniaturised piezo-electric pressure gauge concerning dynamic control and mechanical resistance firing tests will be based on the results of comparison tests in which miniaturised gauges submitted for inclusion are compared with two reference piezo-electric pressure gauges type Kistler 6213 or 6215. The reference gauges will be of the same type (either two Kistler 6213 or two Kistler 6215).

The country testing the equipment for inclusion shall determine which reference piezo-electric pressure gauges shall be used in the comparison tests.

Approval of a miniaturised piezo-electric pressure gauge may be granted for the following configurations:

(a) artillery : maximum range pressure : 500 Mpa

(b) tank gun : maximum range pressure : 800 Mpa

(c) mortar : maximum range pressure : 150 Mpa

Each gauge shall be calibrated and used in accordance with the standard procedure pertaining to that gauge as outlined in ITOP 3-2-810 " Electrical measurement of weapon chamber pressure".

Reference Piezo Electric Gauges shall be located in sufficiently close proximity to each other to enable them to observe essentially the same chamber pressure in the gun or dynamic simulator.

2. TEST REQUIREMENTS

The miniaturised gauge shall be qualified with dynamic control and resistance firing tests at a minimum of 65 % of the measuring range. These tests are mandatory. Then complementary tests may be conducted to qualify the behaviour of the gauge at the upper extremity of the measuring range. For dynamic control and resistance firings tests, at a minimum of 65 % of the measuring range, one or more weapon systems, agreed to by the manufacturer and the country conducting the test, shall be used.

If the manufacturer and the country conducting the tests are the same, agreement with some other NATO countries (chosen by the manufacturer) shall be required.

Prior to tests, the manufacturer and the country conditioning the test shall agree on the planned test pressure levels for each weapon or simulator.

For complementary tests, at the upper extremity of the measuring range, one or more weapon systems or simulators may be used by the manufacturer or the country conducting the tests.

2.1 Dynamic control and resistance firing tests

For the dynamic control and resistance firing tests, the planned test pressure level shall be ≥ 65 % of the measuring range of the miniaturised piezo-electric pressure gauge. A minimum of three miniaturised gauges shall be submitted to comparison with the two reference gauges, at pressure rounds closed to the planned test pressure. For every miniaturised gauge compared with the two reference piezo electric gauges, a minimum sample size of 10 pressure rounds measured by all three gauges must be used in the data analysis after removing the following data from consideration.

(a) Data from pre-test rounds.

(b) Rounds where the pressure difference between the two Reference Gauges will exceed 2% of their mean value.

Acceptance criteria for these tests are reported in paragraph 3.

2.2 Behaviour of the miniaturised gauge at the upper extremity of the measuring range

For these tests, the planned test pressure level shall be ≥ 90 % of the measuring range of the miniaturised piezo-electric pressure gauge. A minimum of three miniaturised gauges should be submitted to comparison with the two reference gauges, at pressure rounds closed to the planned test pressure. For every miniaturised gauge compared with the two reference piezo-electric gauges, a minimum sample size of 10 pressure rounds measured by all three gauges should be used in the data analysis after removing the following data from consideration.

(c) Data from pre-test rounds.

(d) Rounds where the pressure difference between the two Reference Gauges will exceed 2% of their mean value.

A report containing the complete data analysis and results shall be submitted to the appropriate group of experts in the NATO structure for each configuration for which NATO approval is desired.

3. ACCEPTANCE CRITERIA FOR DYNAMIC CONTROL AND RESISTANCE FIRING TESTS

The following procedures shall be applied for each configuration for which NATO approval is desired.

All tests for significance (t-tests) shall be made at the 95 per cent level of confidence.

Estimates of variance shall be computed for each gauge (see paragraph 4).

The two reference gauges must be performing with satisfactory reproducibility and small mean difference to qualify the test as a "valid" test. The test shall be declared "valid" when the reference gauges are found to have satisfactory reproducibility of measurement (Paragraph 4.3) and satisfactory agreement in average readings (Paragraph 4.4).

The test shall be declared "Invalid" when the reference gauges are found to have unsatisfactory reproducibility of measurement or unsatisfactory agreement in average pressure readings (bias).

Once a "valid" test has been conducted, final approval of the miniaturised gauge submitted to test shall be determined based on its performance relative to the average performance of the two reference gauges

gathering the same data. Tests for reproducibility and bias (similar to those just applied to determine a "valid" test) are performed, this time comparing the average reference readings with the miniaturised gauge readings. The miniaturised gauge submitted to test shall have acceptable reproducibility and small bias when it is found to have satisfactory reproducibility of measurement (Paragraph 4.5.1) and satisfactory agreement in average readings (Paragraph 4.5.2). The miniaturised gauge submitted to test shall be declared unacceptable when it is found to have unsatisfactory reproducibility of measurement. This acceptance criteria assumes that the reference gauges and the miniaturised gauge tested shall be located in sufficiently close proximity to each other to enable them to observe essentially the same chamber pressure in the gun. This shall be true for the reference gauges, but may not be for the miniaturised gauge tested, which is located inside the gun chamber. This may cause unexpected systematic and/or random error for this gauge. To insure that reproducibility of random error meets acceptance criteria, the miniaturised gauge tested shall be located in the same place of the chamber gun for all test rounds. It shall be held in position during the rounds to avoid random moves due to pressure variations. In the case where the miniaturised gauge has satisfactory measurement reproducibility but unsatisfactory agreement in average measurement readings (bias), a reason for the bias should be sought. If a systematic error can be detected and explained, the results may be corrected and the analysis repeated beginning at Paragraph 4 below.

The miniaturised piezo-electric pressure gauge shall be declared acceptable when a sample of a minimum of three miniaturised gauges is submitted to the dynamic control and resistance firing tests and each of the submitted gauges is declared acceptable.

A report containing the complete data analysis shall be submitted to the appropriate group of experts in the NATO structure. NATO approval shall be granted for one or more configurations (Paragraph 1) if the miniaturised piezo-electric pressure gauge meets the criteria for reproducibility and bias specified in Paragraph 4.

4. STATISTICAL METHODS

The analysis described below applies to dynamic control and mechanical resistance firing tests. It shall be processed for each miniaturised gauge tested:

- to analyse data of maximum pressure
- to analyse data of rise time between 10 and 90 % of the maximum pressure
- to analyse pulse width at 50 % of the maximum pressure

Specific acceptance criteria for each type of data are reported in related paragraphs.

4.1 Definitions

All observations consist of the sum of three components: the true value (respectively: maximum pressure, rise time, pulse width), instrumental bias error and random error of measurement.

$\mathbf{a_i}$ = ith observation from the first reference gauge (respectively : measured maximum pressure, rise time, pulse width)

$$\mathbf{a_i = X_i + \beta_1 + e_{i1}} \quad \textbf{(1)}$$

$\mathbf{b_i}$ = ith observation from the second reference gauge (resp : measured maximum pressure, rise time, pulse width)

$$\mathbf{b_i = X_i + \beta_2 + e_{i2}} \quad (2)$$

$\mathbf{c_i}$ = ith observation from the miniaturised gauge tested (resp : measured maximum pressure, rise time, pulse width)

$$\mathbf{c_i = X_i + \beta_3 + e_{i3}}$$

$\mathbf{X_i}$ = true value of the ith round (resp : maximum true pressure, rise time, pulse width)

β_j = instrumental bias error of the jth measuring device

$\mathbf{e_{ij}}$ = random error of the measurement of the ith round by the jth measuring device. It is assumed that $\mathbf{e_{ij}}$ is normally distributed with zero mean and variance σ^2_{ej}

When

j = 1, $\sigma^2_{ej} = \sigma^2_{ea}$; j = 2, $\sigma^2_{ej} = \sigma^2_{eb}$; j = 3, $\sigma^2_{ej} = \sigma^2_{ec}$

$\beta_j + \mathbf{e_{ij}}$ = total error measurement of the ith round by the jth measuring device

$\mathbf{n}$ = sample size

$\mathbf{t_o}$ = computed t value of the observed data

$\mathbf{t}$ = significance value from the Student-t Table

4.2 Estimation of variances in error of measurement (reproducibility of random error)

The estimates of variances of random error of the three measuring devices are:

$$\mathbf{s^2_{ea} = s^2_a - s_{ab} - s_{ac} + s_{bc}} \quad (4)$$

$$\mathbf{s^2_{eb} = s^2_b - s_{ab} - s_{bc} + s_{ac}} \quad (5)$$

$$\mathbf{s^2_{ec} = s^2_c - s_{ac} - s_{bc} + s_{ab}} \quad (6)$$

The estimates of reproducibility of the three measuring devices are respectively: $\mathbf{s_{ea}}$, $\mathbf{s_{eb}}$, $\mathbf{s_{ec}}$.
Where

$$s_a^2 = \frac{1}{n-1}\sum_{i=1}^{n}(a_i - \bar{a})^2 \qquad (\text{resp } s_b^2,\ s_c^2) \quad \textbf{(7)}$$

$$\bar{a} = \frac{1}{n}\sum_{i=1}^{n} a_i \quad (\text{resp } \bar{b},\ \bar{c}) \quad \textbf{(8)}$$

and

$$s_{ab} = \frac{1}{(n-1)}\sum_{i=1}^{n}(a_i - \bar{a})(b_i - \bar{b}) \quad (\text{resp } s_{ac},\ s_{bc}) \ \textbf{(9)}$$

For negative estimates of variances in errors of measurement, reproducibility shall be taken as equal to the minimum resolution of the measuring device.

4.3 Comparison of the reproducibility's of the two reference gauges

4.3.1 Definitions

$$H_0 : \sigma_{ea}^2 = \sigma_{eb}^2 \qquad (10)$$

$$t_0 = \frac{r(yz)\sqrt{n-2}}{\sqrt{1-r^2(yz)}} \qquad (11)$$

where

$$y_i = a_i + b_i \qquad (12)$$

$$z_i = a_i - b_i \qquad (13)$$

$$r(yz) = \frac{s_{yz}}{\sqrt{s_y^2 s_z^2}} \qquad (14)$$

s_{yz}, s_y^2, s_z^2 are computed as in formula (7) to (9) in the paragraph 4.2 above.

H_0 is acceptable when $t_{2,5}(n-2) \le t_0 \le t_{97,5}(n-2)$ where $t_{2,5}(n-2)$ is the 0,025 percentile of the Student-t distribution with $(n-2)$ degrees of freedom and $t_{97,5}(n-2)$ is the 0,975 percentile of the Student-t distribution with $(n-2)$ degrees of freedom.

4.3.2 Acceptance criteria

4.3.2.1 Acceptance criteria for maximum pressure

The reproducibilities of the two reference gauges are acceptable if:

$$s_{ea} \text{ and } s_{eb} \leq 1\ \% \left(\frac{\bar{a} + \bar{b}}{2} \right) \left(\text{for mortars : } s_{ea} \text{ and } s_{eb} \leq 3\ \text{MPa} \text{ if } \frac{\bar{a} + \bar{b}}{2} \leq 150\ \text{MPa} \right)$$

4.3.2.2 Acceptance criteria for rise time between 10 % and 90 % of the maximum pressure

The reproducibilities of the two reference gauges are acceptable if:

$$s_{ea} \text{ and } s_{eb} \leq 1\ \% \left(\frac{\bar{a} + \bar{b}}{2} \right)$$

Note: there is not any criteria concerning the pulse width as the value is not known based on previous experience.

4.3.2.3 Complements concerning acceptance criteria

However, when the results of these comparison firings are presented to the appropriate group of experts in the NATO structure for NATO approval, the acceptance or rejection of H_0 will be included in that presentation.

4.3.2.3.1 For maximum pressure

$$\text{If } s_{ea} \text{ or } s_{eb} > 1\ \% \left(\frac{\bar{a} + \bar{b}}{2} \right) \text{ but } \leq 2\ \% \left(\frac{\bar{a} + \bar{b}}{2} \right)$$

$$\left(\text{for mortars : } s_{ea} \text{ and } s_{eb} > 3\ \text{MPa} \text{ but } \leq 5\ \text{MPa} \text{ if } \frac{\bar{a} + \bar{b}}{2} \leq 150\ \text{MPa} \right)$$

the acceptance of H_0 will play an important role in the decision taken by the NATO group of experts.

4.3.2.3.2 For rise time between 10 % and 90 % of the maximum pressure

$$\text{If } s_{ea} \text{ or } s_{eb} > 1\ \% \left(\frac{\bar{a} + \bar{b}}{2} \right) \text{ but } \leq 2\ \% \left(\frac{\bar{a} + \bar{b}}{2} \right)$$

the acceptance of H_0 will play an important role in the decision taken by the NATO group of experts.

If s_{ea} or s_{eb} does not meet the criteria given above or in paragraphs 4.3.2.1 and 4.3.2.2, the reproducibility of the reference gauges shall be declared unsatisfactory.

4.4 Comparison of the average values of the two reference gauges

4.4.1 Definitions

$$H_0 : \beta_a = \beta_b \qquad (15)$$

$$t_0 = \frac{\bar{z}\sqrt{n}}{s_z} \qquad (16)$$

where

$$z_i = a_i - b_i$$

H_0 is acceptable when $t_{2,5}(n-1) \le t_0 \le t_{97,5}(n-1)$ where $t_{2,5}(n-1)$ is the 0,025 percentile of the Student t distribution with $(n-1)$ degrees of freedom and $t_{97,5}(n-1)$ is the 0,975 percentile of the Student t distribution with $(n-1)$ degrees of freedom.

4.4.2 Acceptance criteria

4.4.2.1 Acceptance criteria for maximum pressure

The average pressure readings of the two reference gauges are acceptable if :

either H_0 is accepted or $\left|\bar{a} - \bar{b}\right| \le 1\ \% \left(\frac{\bar{a} + \bar{b}}{2}\right)$

$$\left(\text{for mortars : } \left|\bar{a} - \bar{b}\right| \le 3\ \text{MPa} \ \text{ if } \ \frac{\bar{a}+\bar{b}}{2} \le 150\ \text{MPa} \right)$$

4.4.2.2 Acceptance criteria for rise time between 10 % and 90 % of the maximum pressure

The average rise times of the two reference gauges are acceptable if:

either H_0 is accepted or $\left|\bar{a} - \bar{b}\right| \le 1\ \% \left(\frac{\bar{a} + \bar{b}}{2}\right)$

4.4.2.3 Acceptance criteria for pulse width at 50 % of the maximum pressure

The average pulse widths of the two reference gauges are acceptable if:

either $\mathbf{H_0}$ is accepted or $\left|\bar{a}-\bar{b}\right| \leq 1\ \% \left(\frac{\bar{a}+\bar{b}}{2}\right)$

4.4.2.4 Complements concerning acceptance criteria

If the average readings do not meet the criteria given above in paragraphs 4.4.2.1 and 4.4.2.2 and 4.4.2.3, the average values of the reference gauges shall be declared unsatisfactory.

4.5 Requirements for final approval of the miniaturised gauge tested

4.5.1 Comparison of the reproducibility of the miniaturised gauge tested with the average reproducibility of the two reference gauges

4.5.1.1 Definitions

$$\mathbf{H_0 : \sigma_{ec}^2 \leq \frac{\sigma_{ea}^2 + \sigma_{eb}^2}{2}} \quad (17)$$

$$\mathbf{t_0 = \frac{\left[\frac{s_u^2}{s_z^2} - 0{,}75\right]\sqrt{n-2}}{\sqrt{3\left[1-r^2(uz)\right]\frac{s_u^2}{s_z^2}}}} \quad (18)$$

where

$$\mathbf{u_i = c_i - \frac{a_i + b_i}{2}} \quad (19)$$
$$\mathbf{z_i = a_i - b_i}$$

$\mathbf{H_0}$ is acceptable when $\mathbf{t_0 \leq t_{95}(n-2)}$ where $\mathbf{t_{95}(n-2)}$ is the 0,95 percentile of the Student t distribution with $\mathbf{(n-2)}$ degrees of freedom.

4.5.1.1. Acceptance criteria

4.5.1.2. Acceptance criteria for maximum pressure

4.5.1.2.1. The reproducibility of the miniaturised gauge tested is acceptable if:

either $\mathbf{H_0}$ is accepted or $\mathbf{s_{ec}} \leq \mathbf{1\ \%}\left(\frac{\bar{a}+\bar{b}}{2}\right)$

$\left(\text{for mortars : } \mathbf{s_{ec}} \leq \mathbf{3\ MPa} \text{ if } \frac{\bar{a}+\bar{b}}{2} \leq \mathbf{150\ MPa}\right)$

4.5.1.2.2 Acceptance criteria for rise time between 10 % and 90 % of the maximum pressure

The reproducibility of the miniaturised gauge tested is acceptable if:

either $\mathbf{H_0}$ is accepted or $\mathbf{s_{ec}} \leq \mathbf{1\ \%}\left(\frac{\bar{a}+\bar{b}}{2}\right)$

4.5.1.2.3 Complements concerning acceptance criteria

If $\mathbf{s_{ec}}$ does not meet the criteria given above in paragraphs 4.5.2.1 and 4.5.2.2, the reproducibility of the miniaturised gauge tested shall be declared unsatisfactory.

4.5.2. Comparison of the average value of the miniaturised gauge tested with the average value of the two reference gauges

4.5.2.1 Definitions

$$\mathbf{H_0 : \beta_c = \frac{\beta_a + \beta_b}{2}} \quad (20)$$

$$\mathbf{t_0 = \frac{\bar{u}\sqrt{n}}{s_u}} \quad (21)$$

where

$$\mathbf{u_i = c_i - \frac{a_i + b_i}{2}} \quad (22)$$

$\mathbf{H_0}$ is acceptable when $\mathbf{t_{2,5}(n-1) \leq t_0 \leq t_{97,5}(n-1)}$ where $\mathbf{t_{2,5}(n-1)}$ is the 0,025 percentile of the Student t distribution with $\mathbf{(n-1)}$ degrees of freedom and $\mathbf{t_{97,5}(n-1)}$ is the 0,975 percentile of the Student t distribution with $\mathbf{(n-1)}$ degrees of freedom.

4.5.2.2 Acceptance criteria

4.5.2.2.1 Acceptance criteria for maximum pressure

The average value of the miniaturised gauge tested is acceptable if:

either $\mathbf{H_0}$ is accepted or $\left|\bar{\mathbf{u}}\right| \leq 2\ \% \left(\frac{\bar{\mathbf{a}}+\bar{\mathbf{b}}}{2}\right)$

$$\left(\text{for mortars : } \left|\bar{\mathbf{u}}\right| \leq 5\ \mathbf{MPa} \text{ if } \frac{\bar{\mathbf{a}}+\bar{\mathbf{b}}}{2} \leq 150\ \mathbf{MPa}\right)$$

4.5.2.2.2 Acceptance criteria for rise time between 10 % and 90 % of the maximum pressure

The average value of the miniaturised gauge tested is acceptable if:

either $\mathbf{H_0}$ is accepted or $\left|\bar{\mathbf{u}}\right| \leq 2\ \% \left(\frac{\bar{\mathbf{a}}+\bar{\mathbf{b}}}{2}\right)$

4.5.2.2.3 Acceptance criteria for pulse width at 50 % of the maximum pressure

The average value of the miniaturised gauge is acceptable if:

either $\mathbf{H_0}$ is accepted or $\left|\bar{\mathbf{u}}\right| \leq 2\ \% \left(\frac{\bar{\mathbf{a}}+\bar{\mathbf{b}}}{2}\right)$

4.5.2.2.4 Complements concerning acceptance criteria

If $\left|\bar{\mathbf{u}}\right|$ does not meet the criteria given above in paragraphs 4.5.2.2 the average value of the miniaturised gauge tested shall be declared unsatisfactory.

5 REFERENCES

(1) Engineering Design Handbook, DARCOM-P 706-103, December 1983, Dept. of the Army.

(2) Frank E. Grubbs, "Errors of Measurement, Precision, Accuracy and the Statistical Comparison of Measuring instruments", Technometrics 15, 53-66 (February 1973).