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Force Transducers Relative error of Zero

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ABSTRACT—*This study represent the influence of relative zero error on force proving instruments classification. It is directed to compare the relative zero error resulted from the three loading scenarios applied during calibration of force proving instruments in increasing and decreasing scheme as per ISO 376:2011. It is conclude that the maximum relative zero error resulted after the first loading series at zero position. Two methods are recommended to be proposed as a unique method to calculate the maximum relative error of zero from the first and second loading series or from the preloading series*

Keywords—Force, Calibration, Relative zero error, ISO 376

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1. INTRODUCTION

A force measurement system is made up of a transducer and associated instrumentation. Strictly a transducer is a device that receives a physical stimulus (force) and changes it into another measurable physical quantity through a known relationship. Force transducers are classified according to the type of output signal generated to mechanical, hydraulic, pneumatic or electric transducers [1].

Load cells are one form of electrical force transducers, consist of specially designed structures which perform in a predictable and repeatable manner when a force is applied. The force applied is translated into a voltage by the resistance change in strain gages which are intimately bonded to the transducer structure. The amount of change in resistance indicates the magnitude of deformation in the transducer structure and hence the applied load [2]. Load cells may be characterized as transfer or working standards based on its metrological characteristic resulted from the calibration processes [3].

ISO 376:2011 fourth version [4] cancels and replaces the previous version [5]; there are two calibration schemes according to ISO 376:2011, scheme (A) with increasing and decreasing forces (Figure 1) and scheme (B) with only increasing forces (Figure 2).

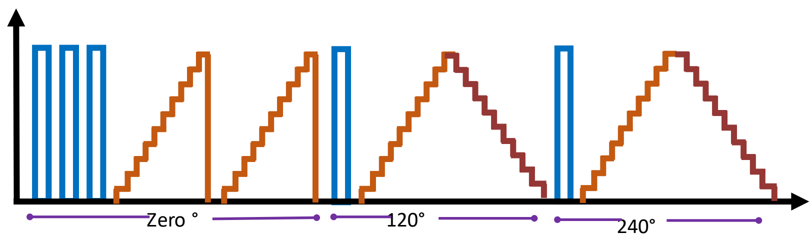

Figure 1: ISO 376 increasing & decreasing calibration (Scheme A)

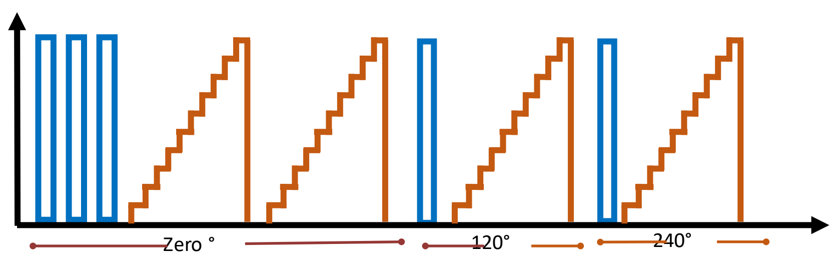

Figure 2: ISO 376 increasing calibration (Scheme B)

ISO 376:2011 calculates and use the relative errors of Reproducibility (b), Repeatability (b`), Interpolation (fc), Zero (f0), Reversibility (v), Creep (c) to classify the force transducers. Table (1) show limits of the relative error in classifying force proving instruments as per ISO 376:2011 [4].

Table 1: Characteristics of the force proving instruments according to ISO376:2011

Class	Relative error of the force proving instrument %					
	Reproducibility	**Repeatability**	**Interpolation**	**zero**	**reversibility**	**Creep**
	B	**b`**	f_c	f_0	**V**	**c**
0	0.05	0.025	±0.025	±0.012	0.07	0.025
0.5	0.1	0.05	±0.05	±0.025	0.15	0.05
1	0.2	0.1	±0.1	±0.05	0.3	0.1
2	0.4	0.2	±0.2	±0.1	0.5	0.2

2. RELATIVE ERROR OF ZERO

The relative error of zero (f_0) is an indicator on the effect of the loading process on the load cell zero output signal. According to ISO 376:2011; it is calculated from equation (1) [4].

$$f_0 = \frac{i_f - i_0}{X_N} \times 100 \qquad (1)$$

Where:
i_f is the reading on the load cell indicator after removal of force.
i_0 is the reading on the load cell indicator before application of force.
X_N is the response corresponding to the maximum calibration force

ISO 376:2011 states that the maximum relative zero error evaluated out of those evaluated after the four test series should be considered in load cell classification [4]. Comparing the four test series resulted from (B) calibration scheme is more logic than comparing the four relative zero error resulted from scheme (A), as the relative zero error is calculated from two different loading scenarios. In the first loading scenario; the maximum force is applied gradually (set of ascending steps) followed by sudden load removal (one step) for two times. In the second loading scenario; the maximum force is applied gradually (set of ascending steps) followed by gradual removal (descending steps) for two times.

3. JUSTIFICATION AND OBJECTIVES

The aim of this experimental investigation is to compare different scenarios in calculating the relative zero error as others directed to rotation effect [6-8]. Three loading scenarios are implemented during calibration according to ISO 376:2011 (scheme A) where the maximum calibration force is applied for nine times (Figure 1). In the first loading scenario; the maximum force is applied suddenly (one step) then it is unloaded suddenly (one step) for five times. In the second loading scenario; the maximum force is applied gradually (set of ascending steps) followed by sudden load removal (one step) for two times. In the third loading scenario; the maximum force is applied gradually (set of ascending steps) followed by gradual removal (descending steps) for two times.

4. EXPERIMENTAL RESULTS

Different load cells with different capacities range from 1 kN to 5000 kN from five different manufacturers (HBM, GTM, Rever, Interface, Matest) were calibrated on a primary (Figure 3) [9] or secondary calibration machines (Figure 4) according to ISO 376:2011 scheme (A) increasing and decreasing forces. Calibration results are analyzed to classify each load cell and determine vales for the nine relative zero errors for each load cell. Table (2) represents the calibrated load cells capacity, class, the values of the nine relative errors of zero and their average value. Results reveal that transducers quite often have a problem with the zero-return after the first series, so they start with a "wrong" zero at the second series.

Figure 3: Example for used primary force standard machines

Figure 4: Example for secondary force standard machines

Table (2): Calculated relative error of zero.

Load cell			Preload					Series				Avg.
#	Cap.	Class	0°1	0°2	0°3	120°	240°	X1	X2	X3 & X4	X5 & X6	
1	1	0	0.0036	0.0004	0.0004	0.0005	0.0008	0.0021	0.0004	0.0003	0.0001	0.0035
2	1	0	0.0025	0.0025	0.0025	0.0029	0.0027	0.0103	0.0076	0.0056	0.0089	0.0077
3	1	0.5	0.0018	0.0018	0.0019	0.0014	0.0011	0.0020	0.0024	0.0026	0.0005	0.0021
4	1	0	0.0100	0.0078	0.0079	0.0023	0.0052	0.0034	0.0098	0.0071	0.0050	0.0077
5	1	out	0.0013	0.0011	0.0004	0.0008	0.0002	0.0016	0.0016	0.0005	0.0012	0.0015
6	2	0	0.0580	0.0000	0.0000	0.0000	0.0145	0.0435	0.0290	0.0145	0.0000	0.0580
7	2.5	0.5	0.0005	0.0010	0.0009	0.0010	0.0017	0.0029	0.0031	0.0022	0.0020	0.0027
8	5	0	0.0007	0.0004	0.0003	0.0005	0.0004	0.0025	0.0012	0.0014	0.0007	0.0022
9	5	0.5	0.0000	0.0000	0.0000	0.0000	0.0003	0.0038	0.0020	0.0004	0.0010	0.0038
10	5	0	0.0135	0.0015	0.0000	0.0000	0.0005	0.0015	0.0005	0.0020	0.0010	0.0135
11	5	0	0.0013	0.0013	0.0013	0.0007	0.0019	0.0035	0.0024	0.0012	0.0020	0.0028

Load cell			**Preload**					**Series**				**Avg.**
#	**Cap.**	**Class**	**0°₁**	**0°₂**	**0°₃**	**120°**	**240°**	**X1**	**X2**	**X3 & X4**	**X5 & X6**	
12	10	0	0.0010	0.0010	0.0010	0.0007	0.0006	0.0030	0.0024	0.0004	0.0004	0.0025
13	10	0	0.0006	0.0008	0.0004	0.0001	0.0010	0.0040	0.0020	0.0000	0.0010	0.0040
14	10	0	0.0006	0.0008	0.0004	0.0001	0.0010	0.0027	0.0020	0.0007	0.0012	0.0025
15	10	0	0.0001	0.0008	0.0007	0.0004	0.0010	0.0048	0.0025	0.0011	0.0009	0.0046
16	10	0	0.0017	0.0017	0.0017	0.0031	0.0030	0.0085	0.0076	0.0046	0.0045	0.0067
17	10	out	0.0016	0.0014	0.0011	0.0013	0.0023	0.0045	0.0046	0.0018	0.0015	0.0035
18	10	out	0.0016	0.0014	0.0011	0.0013	0.0023	0.0045	0.0046	0.0018	0.0015	0.0035
19	20	out	0.0019	0.0015	0.0019	0.0015	0.0011	0.0098	0.0038	0.0034	0.0019	0.0086
20	25	0.5	0.0000	0.0000	0.0000	0.0200	0.0400	0.0000	0.0000	0.0000	0.0000	0.0400
21	25	1	0.0004	0.0004	0.0004	0.0005	0.0016	0.0051	0.0050	0.0006	0.0012	0.0047
22	25	0.5	0.0006	0.0006	0.0006	0.0018	0.0012	0.0002	0.0000	0.0009	0.0007	0.0017
23	25	0.5	0.0005	0.0016	0.0072	0.0014	0.0014	0.0053	0.0047	0.0039	0.0001	0.0071
24	45	0	0.0016	0.0005	0.0005	0.0005	0.0010	0.0021	0.0026	0.0016	0.0068	0.0062
25	45	2	0.0020	0.0015	0.0015	0.0015	0.0020	0.0034	0.0015	0.0113	0.0020	0.0099
26	45	0	0.0076	0.0020	0.0026	0.0023	0.0003	0.0007	0.0010	0.0023	0.0010	0.0073
27	50	0.5	0.0013	0.0012	0.0011	0.0019	0.0031	0.0082	0.0051	0.0036	0.0013	0.0071
28	50	0	0.0009	0.0009	0.0009	0.0023	0.0021	0.0013	0.0011	0.0014	0.0013	0.0014
29	50	0.5	0.0008	0.0008	0.0008	0.0014	0.0002	0.0011	0.0008	0.0011	0.0005	0.0012
30	50	0	0.0009	0.0009	0.0009	0.0028	0.0016	0.0024	0.0015	0.0037	0.0031	0.0027
31	50	0	0.0015	0.0015	0.0015	0.0015	0.0009	0.0001	0.0056	0.0023	0.0020	0.0055
32	50	0.5	0.0009	0.0002	0.0012	0.0000	0.0006	0.0008	0.0010	0.0014	0.0015	0.0014
33	50	0	0.0057	0.0028	0.0019	0.0016	0.0015	0.0013	0.0019	0.0006	0.0001	0.0056
34	50	0.5	0.0013	0.0004	0.0004	0.0004	0.0001	0.0019	0.0010	0.0022	0.0013	0.0021
35	100	0.5	0.0007	0.0007	0.0005	0.0007	0.0012	0.0009	0.0009	0.0008	0.0008	0.0007
36	100	0	0.0665	0.0000	0.0000	0.0886	0.0443	0.0443	0.0443	0.0443	0.0443	0.0886
37	100	2	0.0036	0.0004	0.0004	0.0005	0.0008	0.0021	0.0004	0.0003	0.0001	0.0035
38	100	0	0.0066	0.0017	0.0005	0.0001	0.0005	0.0020	0.0021	0.0028	0.0013	0.0064
39	100	0.5	0.0006	0.0006	0.0006	0.0003	0.0007	0.0013	0.0018	0.0004	0.0005	0.0015
40	200	1	0.0005	0.0005	0.0005	0.0005	0.0004	0.0011	0.0005	0.0012	0.0011	0.0008
41	200	0	0.0008	0.0008	0.0008	0.0008	0.0002	0.0038	0.0026	0.0006	0.0006	0.0036
42	200	0	0.0009	0.0009	0.0009	0.0019	0.0024	0.0039	0.0021	0.0003	0.0006	0.0036
43	200	0	0.0001	0.0000	0.0004	0.0006	0.0006	0.0019	0.0022	0.0011	0.0005	0.0022
44	200	0	0.0000	0.0005	0.0004	0.0028	0.0004	0.0025	0.0019	0.0001	0.0011	0.0028
45	200	1	0.0017	0.0014	0.0010	0.0005	0.0009	0.0026	0.0019	0.0005	0.0001	0.0025
46	250	0.5	0.0021	0.0000	0.0001	0.0015	0.0016	0.0047	0.0062	0.0009	0.0016	0.0061
47	250	0.5	0.0012	0.0012	0.0012	0.0046	0.0044	0.0041	0.0029	0.0007	0.0007	0.0039
48	250	0.5	0.0014	0.0014	0.0014	0.0030	0.0039	0.0035	0.0035	0.0019	0.0009	0.0030
49	445	out	0.0001	0.0008	0.0006	0.0005	0.0006	0.0073	0.0028	0.0008	0.0019	0.0072
50	500	0.5	0.0034	0.0034	0.0034	0.0004	0.0017	0.0045	0.0040	0.0031	0.0039	0.0041
51	500	0.5	0.3501	0.0499	0.0333	0.0331	0.0831	0.0166	0.0498	0.0000	0.0166	0.3501
52	500	out	0.0015	0.0015	0.0016	0.0009	0.0004	0.0039	0.0043	0.0011	0.0006	0.0039

Load cell			Preload					Series				Avg.
#	Cap.	Class	$0°_1$	$0°_2$	$0°_3$	120°	240°	X1	X2	X3 & X4	X5 & X6	
53	500	0	0.0015	0.0018	0.0013	0.0001	0.0013	0.0045	0.0042	0.0011	0.0012	0.0043
54	500	0	0.0002	0.0002	0.0002	0.0021	0.0036	0.0026	0.0037	0.0021	0.0034	0.0035
55	1000	0	0.0002	0.0002	0.0002	0.0039	0.0083	0.0008	0.0002	0.0086	0.0044	0.0084
56	1000	0	0.0009	0.0009	0.0009	0.0008	0.0034	0.0014	0.0003	0.0082	0.0104	0.0101
57	1000	0	0.0001	0.0001	0.0001	0.0008	0.0016	0.0014	0.0012	0.0061	0.0076	0.0075
58	1000	0	0.0018	0.0000	0.0001	0.0005	0.0021	0.0040	0.0023	0.0044	0.0037	0.0044
59	1000	0	0.0023	0.0002	0.0011	0.0057	0.0060	0.0110	0.0109	0.0021	0.0026	0.0108
60	1000	0	0.0000	0.0005	0.0004	0.0028	0.0004	0.0111	0.0103	0.0029	0.0022	0.0111
61	1200	2	0.0019	0.0019	0.0019	0.0038	0.0038	0.0053	0.0047	0.0085	0.0014	0.0071
62	1200	2	0.0023	0.0023	0.0023	0.0023	0.0028	0.0053	0.0050	0.0008	0.0014	0.0046
63	2000	Out	0.0617	0.1387	0.0154	0.0616	0.3082	0.0000	0.0154	0.0462	0.0154	0.3082
64	3000	0.5	0.0062	0.0009	0.0009	0.0019	0.0019	0.0028	0.0033	0.0005	0.0033	0.0057
65	3000	0	0.0028	0.0012	0.0005	0.0009	0.0009	0.0044	0.0000	0.0074	0.0038	0.0074
66	3000	1	0.0065	0.0000	0.0065	0.0130	0.0000	0.0000	0.0000	0.0065	0.0000	0.0130
67	3000	Out	0.0000	0.0154	0.0154	0.0922	0.1076	0.0462	0.0615	0.0154	0.0308	0.1076
68	5000	0	0.0016	0.0016	0.0016	0.0009	0.0008	0.0046	0.0028	0.0004	0.0020	0.0042
69	5000	1	0.0053	0.0053	0.0053	0.0119	0.0079	0.0188	0.0149	0.0035	0.0017	0.0171
70	5000	0	0.0019	0.0019	0.0019	0.0009	0.0015	0.0055	0.0033	0.0002	0.0014	0.0053

5. RESULTS ANALYSIS

Figure (5) shows the distribution of the maximum relative zero error of the seventy load cells. The maximum (f_o) was recorded 25 times after the 1st loading series at zero position, 10 times after the 1st preloading series at zero position, 9 times after the 2nd loading series at zero position and after the 3rd & 4th loading & unloading series, 7 times after preloading series at 120°, 5 times after preloading series at 240°, one time 10 times after the 3rd preloading series at zero position and was not recorded after 2nd preloading series at zero position.

Results reveal that transducers quite often have a problem with the zero-return after the first series, so they start with a "wrong" zero at the second series in a phenomena known by “Late zero effect”.

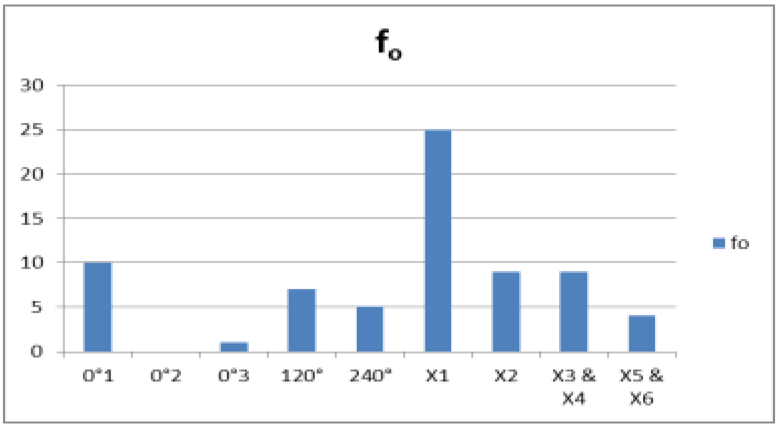

Figure 5: Maximum relative error of zero distributions

To unify a base to calculate the relative error of zero in force proving instruments calibration, five approaches for calculating the relative error of zero are proposed and compared to each other. Table (3) shows the five approaches for the relative error of zero calculations.

Table (3). Proposed groups to unify relative error of zero calculation.

Group	Description
M	The maximum (f_o) evaluated from the 1st and 2nd loading series.
N	The maximum (f_o) evaluated from the 3rd, 4th and 5th preload.
O	The maximum (f_o) evaluated from the 1st and 2nd preload.
P	The maximum (f_o) evaluated from the 1st, 2nd, 3rd, 4th and 5th preload.
Q	The maximum (f_o) evaluated from the (3rd, 4th) and (5th, 6th) loading & unloading.

Regrouping the results in Table (2) as per the proposed approaches listed in Table (3) shows that; Group (M) is more representative than the other group as it represents 48.6 % of the maximum relative error of zero while group (O) is the less representative. Table (4) represents the probability of occurrence of maximum relative error of zero and Figure (6) represents the number of occurrence of maximum relative error of zero out of the seventy load cells

Table 4: Probability of maximum relative error of zero occurrences.

Group	Probability of max. f_o
M	48.6 %
N	18.6 %
O	14.3 %
P	32.9 %
Q	18.6 %

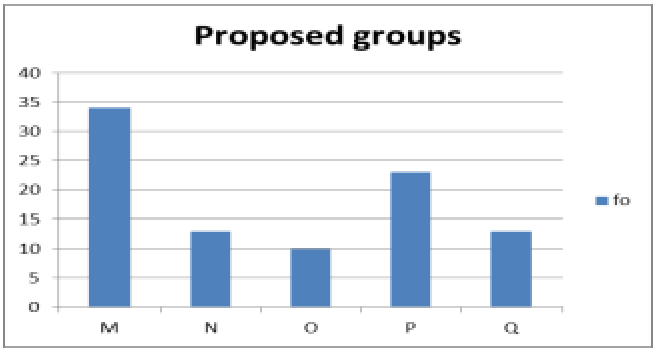

Figure (6): Maximum relative error of zero according to the proposed groups

Based on the results and analysis it is proposed to calculate the maximum relative error of zero from the 1st and 2nd loading series (Group M) or from the 1st, 2nd, 3rd, 4th and 5th preload (Group P) and to indicate in the calibration certificate the method used to calculate the relative error of zero.

6. CONCLUSION

As a result of evaluating the results it is concluded that the maximum relative zero error was after the first loading series at zero position, this problem with the zero-return after the first series, lead to start with a "wrong" zero at the second series, increasing the time between the end of the first loading series and the start of the second loading series may help to reduce the late zero effect.

Two methods are recommended to and proposed as a unique method to calculate the maximum relative error of zero from the first and second loading series or from the preloading series, the selected method must be documented and certified in the calibration certificate as same as stating the relative creep error calculation method.

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