# 로드셀 출력에 미치는 하중틀 크기의 영향
# Effect of the Loading Frame Dimensions on the Loadcell Read-out

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## 1. Introduction

In the international comparisons of deadweight force standard machines in national metrology institutes, the maximum relative deviations were about ± 5 × $10^{-5}$ in the worst case while the theoretical uncertainty of a deadweight force machine is less than 1 × $10^{-5}$. This discrepancy has been ascribed to the interaction between DWMs and transfer standards, measurement procedure and parasitic force components of DWMs. Among them, the DW M-loadcell interaction is a significant factor of the discrepancy, therefore should be investigated.

Several studies had been established to investigate the interaction between the DWM and the loadcells. As a result, it was suggested that the main reasons propagate the interaction between the DWM and loadcell can be classified into three main categories. These three categories are force application [1-4], vibrations [5], and environmental conditions [1].

In this investigation, we are willing to know the influence of the loading frame stiffness through finite element method. FEM modelling has to be run with different force application criteria, and different dimensions of loading frames. Two force criteria were chosen to be applied on the simulation with $0^O$ and $1^O$ inclination angles. In addition, different dimensions of loading frame have been dedicated to run the experiments. Targeting confirmation of the modelling results and introducing rigid evidence that results are generally applicable for all kinds of loadcells, experimental measurements have been established and examined using the same FEM conditions. In order to fulfill all conditions of recent investigation, complementary FEM modeling followed by measurements have been established to give the conclusions a more respected and generalized meaning.

## 2. FEM Simulation

Regarding the establishment of the framework of the investigation, many factors should be discussed and selected and hence the steps of the modeling could be arrayed. First item to be analyzed to its main factors is the loading frame construction, which simply can be classified into; upper plate, lower plate and column, while the second item to be analyzed in the investigation is the loadcell. With the aim of joining all these factors in the investigation thousands of experiments should be run. Therefore, the importance of using a way to decrease the number of processes took its place, and Taguchi method introduced itself as a brilliant solution for compressing the number of processes. Consequently, a series of FEM simulations were carried out using 324 models.

The application of Taguchi method starts by defining the factors that affect the loading frame stiffness, from point of view of dimensions. In order to simplify the measurement process and to reduce the cost, effort and hence the time, a preparatory FEM simulation were ran and the results suggested the effectiveness of four dimensions, which are upper plate thickness, *h*, span width, *L*, loading frame height, *H*, and column diameter, *d*. Moreover, in order to superimpose all combinations of different force application criteria ($0^O$, and $1^O$ inclinations), different shapes of loadcells (three shapes), and different dimensions of loading frames, and since this required a large number of experiments the Taguchi method with an $L_{27}$ orthogonal array (OA) has been selected and used [6].

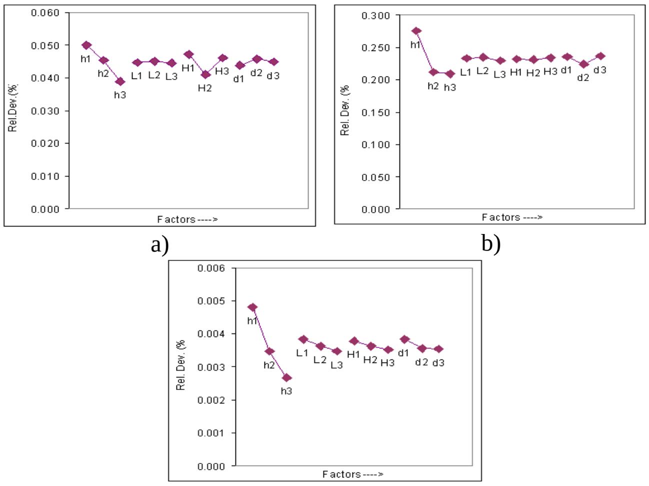
To run such simulations, the upper plate thickness, *h*, was considered and dimensions of 12, 16, and 20mm were estimated. In addition, the diameter of the loading frame columns, *d*, were estimated as 4, 8, and 10 mm, the span width of the loading frame, *L*, was estimated as; 100, 150, and 200 mm. Finally, the loading frame height, *H*, was sat as three values; 200, 300, 400 mm.

The simulations were run by applying the loads on the loading frame-loadcell model and deducing the behavior of the model by comparing the results of four practical strain gauges positions distributed all over the loadcell sensing element.

The relative deviation between $0^O$, and $1^O$ inclination was chosen to be the results extracted from the measurements.

## 3. FEM Results

The resultant data raised from the FEM simulations graphed in figure 1 and consequently the relative contribution of variables, using ANOVA, has been calculated and tabulated in table 1.




a) b) c)

Fig. 1 FEM resultant relative deviation of a) Beam-type loadcell, b) Column-type loadcell, and c) S-Type loadcell (ideal and average of $0^O$, $120^O$, $240^O$ rotations)

Table 1 The factorial relative contribution for the FEM results

| | | Factorial Relative Contribution (%) | | |
|---|---|---|---|---|
| | | FEM Simulation | | |
| | | $A_1$ (Beam ) | $A_2$ (Column) | $A_3$ (S-Type ) |
| Percent of *h* | $P_h$ | 72.61 | 96.04 | 93.91 |

Where, the $A_1$, $A_2$, and $A_3$, are the averages of the relative deviation of the FEM results taken with rotation in three positions $0^O$, $120^O$, and $240^O$ for the Beam, Column, S-Type loadcells.

If we have an examiner overall look to Fig. 1 a), b), and c) a clear trend of the *h*, upper plate thickness, took its place as a common trend among all other factors. This trend clearly suggested that, under any inclination between the application point of force and loadcell centerline the more the thick of the upper plate is the less the deviation from the ideal position are. While the percentage of contribution of *h*, illustrated in Table 1, is big enough to neglect the contributions of other dimensions.

The previous conclusion not only a good help for the manufacturers during design of DWMs but one can go through more general principle which suggests the preference of the low stiffness of the loading frame comparing to high stiffness.

## 4. Experimental Verification

In order to grant the simulation outcome more generalized value, a series of experimental measurements were carried out using 54 different models. These verifications are responsible for applying the measurements using the same designs of the FEM. The strategy used in the FEM simulations has been repeated in the experimental measurements, and the Taguchi method with an $L_{27}$ OA has been re-performed by using the same conditional dimensions of *h*, *L*, *H*, and *d*.

However to achieve such measurements, three models of loading frames were designed and manufacturing. The designed loading frames has the ability of changing the span width between three different lengths 100, 150, and 200 mm. In addition, the designed frame has the ability of changing the upper plate thickness with 3 different thicknesses; 12, 16, 20 mm. The columns were manufactured and grouped into three groups; 200, 300, and 400 mm height respectively. Each group consists of three subgroups with 4, 8, 10 mm diameters respectively, each has 3 columns.

A well specified, stable, and historically defined transfer standard with capacity of 200 N were selected to run the measurements using the 27 trials. The measurement protocol is basically consists from three preload cycles followed by one loading cycle at $0^O$ and two loading cycles at $120^O$ and $240^O$, each preceded by a preload cycle.

The results acquired from the experimental verification process assured the concluded results obtained by the FEM modeling. The trend of the *h*, upper plate thickness, took its place as a common trend among all other factors. Moreover, the dominancy of the upper plate thickness over other factors is tremendously observed with value equal to 93.44%, which neglects percentage of contributions of other factors. The experimental results obtained by the measurements suggested clearly that the results gained by FEM

## 5. Tracing the Effect of Upper Plate Thickness

Now the upper plate thickness, *h*, has proven it self as the dominant factor of the loading frame dimensions. However, in order to define the exact behaviour of the loadcell output when exposed to loading frames with miscellaneous upper plate thicknesses, in addition to specify the safe zone during implementing the designing process of DWMs, a series of generalizing simulations have been carried out using FEM program.

To run such simulations, the upper plate thickness, *h*, was considered and dimensions of 4, 8, 10, 12, 14, 16, 18, 20, 22, 24, and 26 mm were estimated. While values of *b*, *d*, and *H*, were fixed to it their averages, i.e. 10, 8, and 300 mm respectively.

One more additional hypothesis, that to make comparison between different upper plate thicknesses, which assumed up till now has a rectangular cross sectional area, we are in need to insert the value of the cross section area in the comparison process. Such assumption will facilitate the comparisons even between different shapes of upper plate cross sections. Therefore, the calculations will base on the using of the second moment of inertia of the upper plate thickness with respect to the generated force. This relative term can be expressed in $I_X/F$ ($mm^4/N$), where $I_X$ is the second moment of inertia and $F$ is indicating the generated force. By applying the rated force equal to 200 N, this will set the relative term ($I_X/F$) to equal 0.27, 2.13, 4.17, 7.2, 11.43, 17.07, 24.3, 33.33, 44.36, 57.6, and 73.23 $mm^4/N$ respectively.

The column type loadcell was chosen to be the model used in the present simulation. In addition, the same circumferential loading cases used in section 2 were repeated. The results of these 11 verification modelling were graphed in Fig. 2.

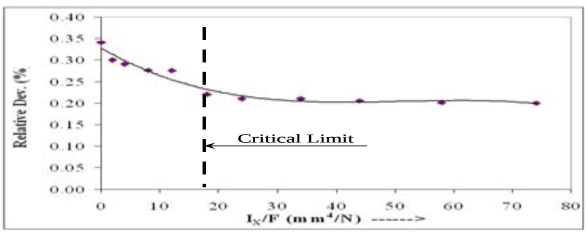



Fig. 2 Relationship between the relative deviation and $I_X/F$

It may be concluded from the previous graph that the less the second moment of inertia is, the better the relative deviations are. In addition, it is clear that the difference in magnitude of the relative deviations when $I_X/F > 18$ $mm^4/N$ (which is approximately comparable to *h*=16 mm) can be ignored comparing with that when $I_X/F < 18$ $mm^4/N$.

In order to confirm the consistency of the previous FEM results as well as make the conclusions applicable for all types of DWMs, a set of experimental measurements were conducted using two transfer standards with capacities of; 20 kN and 200 N, along with 3 DWMs with rated forces 100 kN, 20 kN, and 200 N respectively.

The measurement protocol, basically, consists from three preloading cycles followed by three data-loading cycles at $0^O$ and another two data-loading cycles at $120^O$ and $240^O$ respectively, each preceded by one preloading cycle. The data-loading cycles at $0^O$, $120^O$, and $240^O$ were repeated 3 times. In addition, two loading criteria have been chosen which are; $0^O$ and $0.2^O$ inclination angles.

The results obtained from the generalization measurements showed relative deviations equal to 5, 8, and 20 ppm for the 100 kN, 20 kN, and 200 N respectively. The outputs were clearly suggested the preference of the output gained from the 100 kN DWM over other DWMs. Although the difference is considerably small between the 100 kN and the 20 kN DWM, but the trend remains yet and the conclusions is applicable for all types of DWM.

## 6. Conclusion

This paper considered as first of series of investigations, which aim to outline guide for the DWM builders by unveiling the term of DWM-Loadcell Interaction. The most important conclusion from this investigation is the importance of the upper plate thickness and its superiority over all other loading frame components, and consequently the priority of the rigid loading frame. In addition, the upper plate thickness must be equal a value that meet the condition $I_X/F > 18$ $mm^4/N$.

For activating more research in DWM-Loadcell interaction, another investigation that suggest another way of focusing on the stiffness of the loading frame construction rather than modification of dimensions, e.g. different materials for both loading frame and loadcell. More researches should be conduct to compare the results obtained by the generalization simulation using Column-Type loadcell is applicable to other types of loadcells and for what extend.

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## References

1. Bray A., Barbato G., and Levi R., “Theory and Practice of Force Measurement,” ed Quinn T J (London: Academic Press), 1990.
2. Robinson G. M., “The Influence of Contact Stresses on Cylindrical Strain Gauge Load Cells,” Proc. IMEKO 14th, Warszawa, 129-134, 1995.
3. Ferrero C., Marinari C., and Martino E., “A Six-Component Dynamometer to Measure Parasitic Load Components on Deadweight Force Standard Machines,” Proc. IMEKO 10th, Kobe, 199-204, 1984.
4. Park Y. K., Kim M. S., Kim J. H., and Kang D. I., “A Proposal for an Evaluation Method of Force Standard Machines by Using Build-Up System,” Proc. IMEKO-TC3 19th, Cairo, 001, 2005.
5. Nakatani M., Kameoka K., Komatsu G., Inui N., Naito K., Konishi H., and Shimomae Y., “Effect of Floor Vibration on a Double-Beam Type Loadcell Scale,” Proc. IMEKO 16th, Taejon, 460-467, 1998.
6. Ranjit R., “A Primer on the Taguchi Method,” New York: Van Nostrad Reinhold, 1990.