

Modifications to the NPL Bullion Balance

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ABSTRACT

NPL's Mass Section has over the years made many modifications to its 310 kg capacity equal arm balance, known as the Bullion balance. Assessment of these progressive modifications has shown that the balance's performance has not been significantly improved, leading to the conclusion that the balance has achieved the limit of its performance.

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1 INTRODUCTION

NPL's bullion balance is a 310 kg capacity equal arm two pan balance manufactured by Oertling. The bullion balance is used by Mass Section for the calibration of mass standards above 50 kg up to its capacity. Its principal use is in the calibration of the weights for Force Section's deadweight force standard machines, providing traceability to the UK primary kilogram. The balance has been in use at NPL for over 30 years, and has been extensively modified over this period. This report describes these modifications and assesses their success in improving the performance of the balance.

2 DETAILS OF THE MODIFICATIONS

2.1 BALANCE INDICATOR UNIT

In 1985 a diode array and balance indicator unit were added to the balance. This is an optical system used to increase the resolution and automate the detection of turning points for two pan balances. The system works by projecting a light source via a prism and angled mirror onto a concave mirror mounted centrally on top of the beam. The concave mirror reflects and focuses the light to produce a spot on a photo-diode array housed above the balance (see Figure 1). The position of this spot corresponds to the angular displacement of the beam. The output from the diode array is relayed to an indicator display box which detects the change in direction of the spot, and thus the turning point of the swing, and displays it numerically. The balance indicator unit has a scale range of 10 000 units, with the mid point of the scale, 5 000 units, indicating when the beam is horizontal.

Figure 1: Balance optics

Before the balance indicator unit was introduced the turning points of the balance were read from a pointer scale by the operator. The scale has 20 divisions and with a keen eye these divisions could be subdivided 10 times (a scale range of 200 units). The balance indicator unit has improved the readability of the balance from ~50 mg per scale unit to ~1 mg per scale unit, therefore improving the resolution of the balance 50 times, as well as removing any operator error from reading the scale.

2.2 CROSS KNIFE DECOUPLING

In 1987 a cross knifed universal pivot was fitted between the pan and the terminal knife. This was introduced to further decouple the pan from the beam and reduce the sensitivity of the balance to off centre loading. The addition of this decoupling pivot had no significant effect in improving the performance of the balance.

2.3 REFURBISHMENT OF BALANCE ARRESTMENT MECHANISM

In January 1993 a new three point arrestment mechanism for the terminal planes of the balance beam, designed and built by NPL Engineering Services, was fitted to the bullion balance, to replace the existing two point mechanism. It was hoped that the new kinematic three point mechanism would improve the reproducibility of the point of contact between the terminal planes and knives.

2.3.1 Adjustment of new arrestment mechanism

After fitting the new 3 point arrestment mechanism the following adjustments were made. The central knife attached to the beam was adjusted to be parallel to the central plane by measuring the gap between the plane and knife edge at the central fulcrum using feeler gauges. The central knife/plane gap was adjusted to be parallel and approximately 60 μm . The terminal planes were adjusted using the new 3 point mechanism to be horizontal and give a parallel knife/plane clearance of approximately 20 μm . Therefore in theory the terminal planes will touch their knives before the central knife does, so the beam is arrested when the terminal knives make contact (this may not have been happening before). The balance was then poised at zero load using make-weights (not the poising “lever” on the beam), and the optical array system re-aligned.

2.3.2 Assessment of new arrestment mechanism

The performance of the balance for the calibration of set NPL W 58 (100 kg slab weights), using the balance in substitution mode, was compared before and after the refurbishment.

	Before New Arrestment Mechanism	New Arrestment Mechanism
	(mg)	(mg)
σ_{n-1} (n=8)	120 -140	150 - 200

Table 1: Standard Deviation for the Repeatability of Weighing Two 100 kg Weights

Table 1 shows the standard deviation of results obtained from 8 repeated calibrations of two 100 kg standard weights. The results show that the refurbishment of the arrestment mechanism has made no improvement to the repeatability of weighing. It has in fact made it worse but not significantly.

2.4 MODIFICATION TO ALLOW WEIGHT EXCHANGE WITHOUT ARRESTMENT

The modifications, described below, were designed to allow the weights on one of the scale pans to be exchanged without having to arrest the balance. This allows the terminal knives to be kept in contact with the planes, and maintain the distance the weights are from the balance fulcrum constant throughout the entire weighing scheme. By achieving this the balance should theoretically give repeatable results.

These modifications were specifically designed for use with 1 kN slab weights from the Hong Kong Government deadweight force machine (a project NPL was commissioned to build). The large number of these weights (over 50) requiring calibration necessitated that the repeatability of the balance be improved to minimise the number of weighings which would be required to assign a 3 ppm uncertainty to these weights.

2.4.1 Description of modifications

The modifications (Figure 2 shows the modifications for use with conventional masses) consist of two T-shaped weight supports, bolted to the ground at the front and rear of the scale pan. A horizontal cross section, running between the two supports, mounts a motor and jack system directly under the centre of the scale pan. The jack is coupled to the scale pan via a loop and hook arrangement with enough clearance to allow a full scale swing. The jack and motor system pulls the scale pan below the weight supports, counter balancing the other pan whilst the weight is exchanged (with the knives and planes still in contact). The 1 kN deadweights are located on the scale pan using kinematic mounts therefore when the scale pan is brought back up to the weight supports it will pick each deadweight up in the same position.

2.4.1 Assessment of new modifications

The balance was assessed in substitution weighing mode by the repeated weighing of a 1 kN deadweight. The balance was pre-loaded at zero, 1 kN, and 2 kN loads (to assess the performance at various loads), comparing the arrestment mechanism of the balance with the new modifications.

Pre-load	Standard Deviation of 5 Repeated Weighings (mg)	
	Using Arrestment	With Modifications
Zero	127	110
1 kN	59	56
2 kN	39	20

Table 2: Standard Deviation of 5 Repeated Weighings of a 1 kN deadweight.

The results in Table 2 show that the modifications again have made no significant improvement to the balance's repeatability at a zero pre-load, however as the pre-load is increased the performance is considerably improved. Since the balance and all its components are designed for weighing at its capacity, it is understandable that it is at this load where it will perform best.

2.5 MODIFICATION FOR CONVENTIONAL MASS STANDARDS

The modifications for weighing conventional mass standards (see Figure 2) use the same arrangement as that designed for weighing the 1 kN Hong Kong deadweights except an additional plate has been introduced to sit on the scale pan and span the weight supports. This additional plate also uses kinematic mounts for location on the pan.

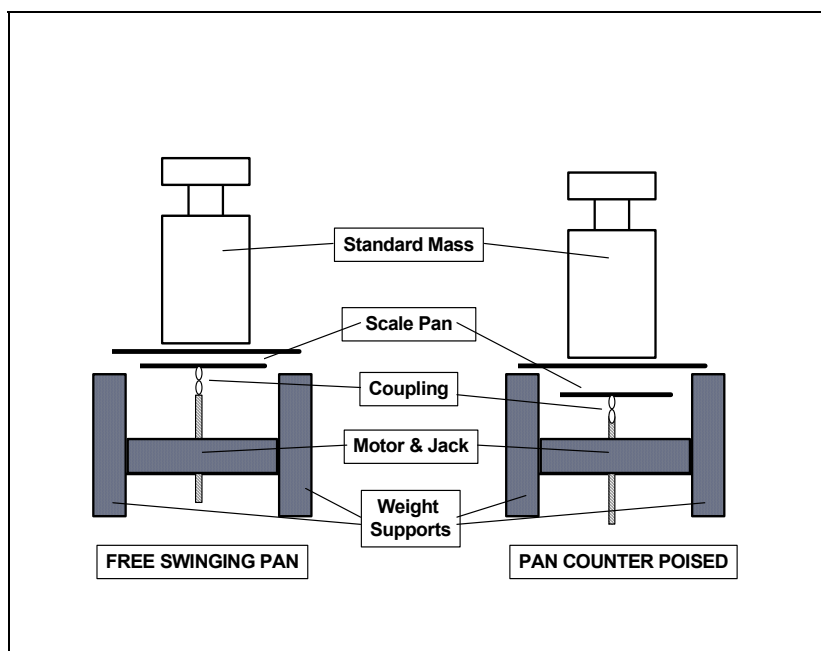


Figure 2: Weight exchanging modifications for mass standards

2.5.1 Assessment of new modifications

The balance was assessed in a similar way as was carried out for the 1 kN modifications. 100 kg mass standards were compared in substitution mode at three loads instead of deadweights.

Pre-load	Standard Deviation of 5 Repeated Weighings (mg)	
	Using Arrestment	With Modifications
Zero	101	472
100 kg	36	306
200 kg	114	147

Table 3: Standard Deviation of 5 Repeated Weighings of a 100 kg mass standard.

The results in Table 3 are considerably poorer and more random than those obtained from the previous tests. They show that the new modifications have not improved the performance of the balance, and loosely follow the trend that the balance works better when pre-loaded.

3 CONCLUSIONS

All the assessment tests show similar performance results apart from weighing conventional mass standards using the new modifications, which gave particularly poor results compared to using the 1 kN deadweights. An explanation for this may be the difficulty experienced when loading the scale pan. With the tight loading restrictions imposed by the new modifications it is impossible to place conventional mass standards centrally on the pan, using the existing lifting apparatus, and this seemed to have a fouling effect on the pan and jack coupling. This problem did not arise with the 1 kN deadweights as they could be loaded differently. Therefore if a method of loading the pan centrally can be found the system should perform as well as it did with the 1 kN weights however this still does not represent a significant improvement on the original arrestment mechanism.

In conclusion apart from the introduction of the balance indicator unit, which improved the resolution, all the modifications which have been made to the bullion balance's physical design over the years have made no significant improvement to its performance. It is therefore concluded that the limit of the balance's performance (1 ppm uncertainty on masses of 100 kg to 300 kg with many repeated weighings when the balance is used close to its capacity) has been reached and no obvious improvement can be made to it.

4 ACKNOWLEDGEMENT

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