

Design and Assessment of an Automatic 50 kg Weight Exchanger

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ABSTRACT

The following report outlines the tests which were conducted to assess the suitability of a commercially available top pan electronic balance for use with an automatic weight exchanging mechanism. The conceptual design, manufacture and testing of the weight exchanger are described and the current performance of the system discussed. Suggestions are made for future work on the balance with a view to further improving its performance.

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Appendix 1

1 INTRODUCTION

NPL's Mass Section has a large number of 50 kg mass standards (26 in total) which require maintaining, and has to provide traceability to the UK primary kilogram for a larger number of Force Section's deadweights. Mass Section has two balances in this range, the Poynting (an equal arm two pan balance) and the Sartorius C60000S (an electronic platform balance). For the calibration of all these weights, using the Poynting is very time consuming and unsuitable for awkwardly shaped deadweights, and using the Sartorius does not provide the accuracy required. Mass Section therefore had a requirement to improve the accuracy of the Sartorius balance and to make the calibration of these weights more efficient by automating the process.

2 ASSESSMENT OF A COMMERCIAL PLATFORM BALANCE

A Sartorius C60000S Electronic Platform balance was evaluated to assess its suitability for use with an automatic weight exchanger mechanism to produce a fully automated balance.

The basic balance was tested for repeatability, eccentricity, and hysteresis, using the balance conventionally (as supplied) and removing its A-frame and self centring cradle and using it as a platform balance.

2.1 Repeatability

The repeatability was assessed by manually removing and replacing a weight on the balance ten times. Readings of the zero as well as of the load were taken, so any drift could be measured and accounted for. The repeatability check was initially performed at 50 kg and 10 kg load. Further tests were performed with a 50 kg weight remaining on the balance whilst applying and removing a 5 kg weight and comparing 5 kg and 10 lb weights. These further tests were conducted to find out if maintaining a near constant (full) load on the balance made any significant difference to its repeatability. The results for these tests are given in table 1.

Load		Weighing Cradle	Platform
50 kg	Std dev (mg)	50	66
	Max diff (mg)	145	230
10 kg	Std dev (mg)	10	16
	Max diff (mg)	30	50
50 kg + 5 kg	Std dev (mg)	8	6
	Max diff (mg)	20	20
50 kg + 5 kg/10 lb	Std dev (mg)	6	8
	Max diff (mg)	20	20
5 kg	Std dev (mg)	10	
	Max diff (mg)	35	
5 kg/10 lb	Std dev (mg)	10	
	Max diff (mg)	35	

Table 1: Results of repeatability assessment

The results show that weighing with the cradle gives better results than the platform. Since weighing using the cradle can compensate, to a certain degree, for off centre loading (see section 2.2), this implies that repeatable positioning of the weight is critical in order to obtain repeatable results. At lower loads the balance is also found to be more repeatable, again this may be due to positioning, as it is easier to manually handle smaller lighter weights. This is again shown by the results obtained from the comparison of 5 kg and 10 lb weights, and the addition and removal of a 5 kg weight, with the balance loaded at 50 kg. Here the bulk of the load is kept in the same position, with only the smaller weights being applied and removed, therefore the load is always passing through the same position on the balance.

When the balance was used to compare two 50 kg weights it began to give unstable readings, in both modes, after several exchanges.

2.2 Eccentricity

The sensitivity of the balance to load position was checked by placing a 20 kg weight at front, back, left and right positions around the pan. This method was followed with both the self centring weighing cradle in place and removed (concentric circles were marked on the pan to aid the positioning of weights).

With the self centring cradle removed the dependence of the balance reading on distance from the centre was also checked.

	Cradle	Platform	Platform	Platform
		2 cm	4 cm	6 cm
	Difference relative to centre rdg	Difference relative to centre rdg	Difference relative to centre rdg	Difference relative to centre rdg
Right (mg)	-50	-55	-220	-375
Front (mg)	+40	+50	+880	+2130
Left (mg)	-20	+130	+135	+170
Back (mg)	-40	-215	-460	-825

Table 2: Results of eccentricity assessment

The results show there is a marked difference in the sensitivity of the balance to off centre loading between the two different weighing modes. When using the weighing cradle the differences relative to the centre reading at each of the four points are small and similar in magnitude. Whereas when used as a platform balance the differences vary markedly, which shows that the cradle does have an effect on correcting for off-centre loading. In comparing the dependence on distance of off centre loading, the further a weight is moved from the centre the bigger the difference becomes, and the effects are more pronounced in certain directions. This shows the poor performance of a single load cell comparator with respect to eccentric loading.

2.3 Hysteresis

The hysteresis was checked by taking readings for both increasing and decreasing loads using three weights of approximately 15 kg. The load of the balance was not allowed to go back to zero between readings. The results for these tests are shown in Table 3 and displayed in Figure 1, they represent the difference in the balance reading from actual mass of the weights.

Load (kg)	Series 1 (g)	Series 2 (g)	Series 3 (g)	Series 4 (g)
0	0.00	0.00	0.00	0.00
15	-0.01	0.02	0.05	0.03
30	0.04	0.03	0.07	0.00
45	-0.03	-0.02	0.11	0.05
30	-0.23	-0.22	-0.18	-0.23
15	-0.30	-0.27	-0.23	-0.27
0	0.02	0.03	0.03	0.03

Table 3: Results of hysteresis assessment

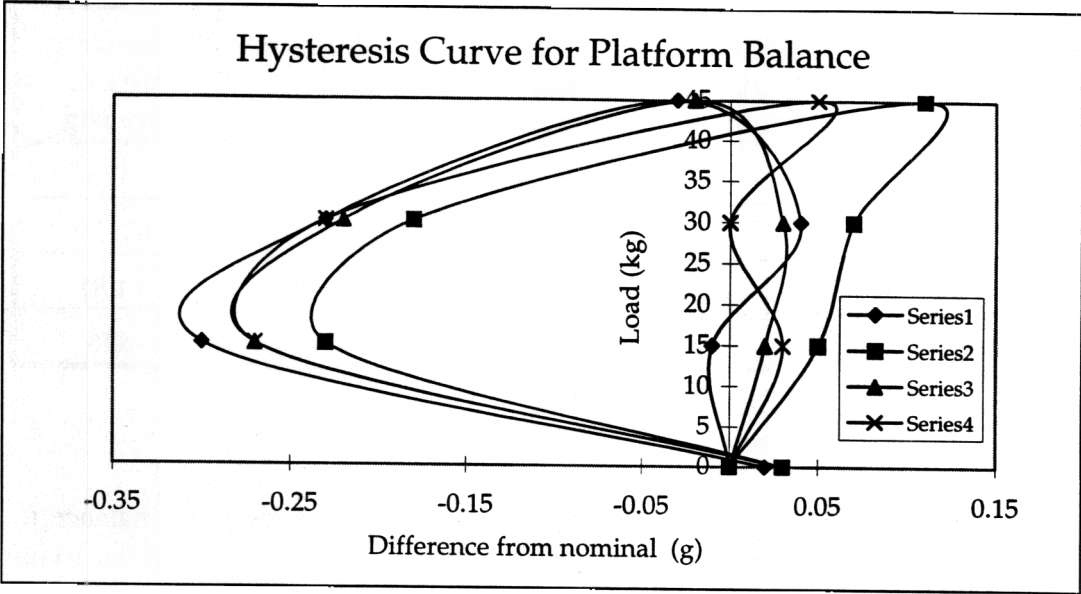


Figure 1: Plot of results of hysteresis assessment

Figure 1 illustrates the effects of hysteresis shown by the balance. The y-axis represents the actual load applied to the balance and the plotted points (taken from Table 3) the deviation from this value. The points on the right hand side of the graph represent the load increasing and the points on the left hand side the load decreasing. The results obtained from the four series of tests all display a similar hysteresis curve, and illustrate the difference in balance readings obtained from increasing and decreasing the applied load. The hysteresis was calculated to be $>0.001\%$ a mass equivalence of about 500 mg in 50 kg.

2.4 Conclusion

From the three tests used to assess the balance it can be concluded that the balance is highly susceptible to both off-centre loading and hysteresis. In order to improve the performance of the balance it requires a good self-centring device and a mechanism for exchanging weights with a near constant load.

3 MODIFICATION OF BALANCE

3.1 Self-Centring Device

3.1.1 Description

A commercially available “level-matic” pan was purchased from Mettler Toledo Ltd. The “level-matic” pan consists of a race of ball bearings held between concave and convex plates. This arrangement allows the top plate to tilt and swing to bring the centre of gravity of the load to the same position each time. The balance was assessed

for repeatability using this device by comparing the results with those previously obtained.

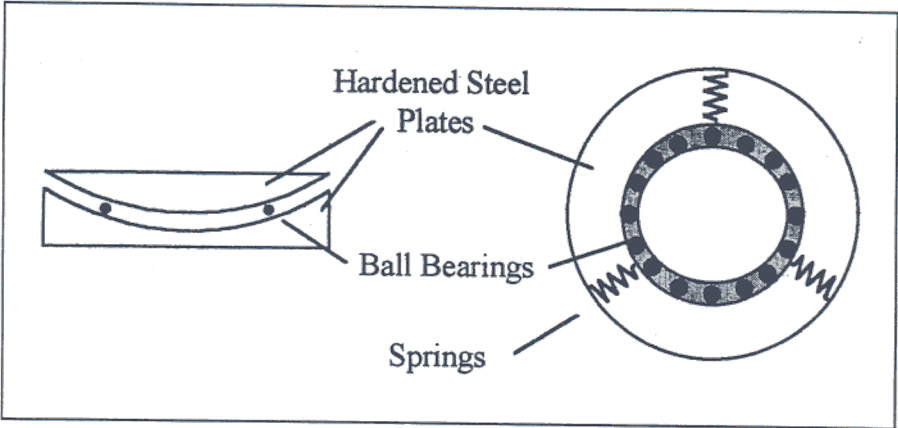


Figure 2: “level-matic” pan

3.1.2 Assessment

Table 4 shows the results of 10 repeated weighings at two loads comparing the balance used with and without the “level-matic” pan.

Load		Results using Level-matic Pan	Previous Results
10 kg	Std dev (mg)	15	16
	Max diff (mg)	45	50
50 kg	Std dev (mg)	28	66
	Max diff (mg)	120	230
50 kg Comparison (1)	Std dev (mg)	47	
	Max diff (mg)	140	
	Error (mg)	58	
50 kg Comparison (2)	Std dev (mg)	19	
	Max diff (mg)	50	
	Error (mg)	29	

Table 4: Repeatability assessment with the “level-matic” pan

The results in Table 4 show that the 10 kg results are comparable. However the “level-matic” pan has made a significant improvement to the repeatability at 50 kg, and the balance was able to be used as a comparator without giving unstable readings (unlike in section 2.1). The second set of comparison results were recorded taking more care to position the weight centrally on the “level-matic” pan, and these show an

improvement on the results obtained from the first comparison. Although the pan can swing and hence shift the centre of gravity of the weight, there is only a limited travel in the system, therefore it may not be able to bring the weight's centre of gravity to the same position each time if the weight is placed at the pan's extremes.

3.1.3 Conclusion

The introduction of the “level-matic” pan has significantly improved the repeatability of the balance and it has been observed that, if care is taken when positioning the weight, the performance can be further improved.

3.2 Weight Exchanger

3.2.1 Conceptual Design

On analysis of the assessment data the two major drawbacks with the balance which needed to be addressed in the design of an automatic weight exchanging system were: placing the weights centrally and repeatably on the pan, and keeping a constant load on the balance when exchanging the weights in order to eliminate any hysteresis in the balance.

A conceptual design for a weight exchanger had to fulfill the following functional requirements.

- The framework and cradle has to provide a structure strong enough to support 50 kg without significant flexing.
- The cradle itself can weigh no more than 10 kg. This 10 kg limit is required as the balance has 60 kg capacity on its own and the cradle will be in constant contact with the weighing pan so reducing the usable range to 50 kg.
- The material used has to be non-magnetic and non abrasive, since it has to come into contact with mass standard artefacts.
- The weight exchanger is required to calibrate force machine deadweights, which are not of regular sizes or dimensions, and the top station has to be an open platform large enough to accommodate these types of weights. The bottom station can be more restricted in access provided it can accommodate a standard 50 kg knob weight.

The control system requirements are for both manual and automatic control. In order for the exchanger to keep as constant a load as possible on the balance the stepping motor speeds should be variable and the software should use a feed back system from the balance readout instead of stepping the station synchronously.

3.2.2 Tendering

These functional specifications were put out to tender to two organisations. Two bids were received, and a contract was awarded to Sulcated Springs Ltd (SSL) for the manufacture of a weight exchanger and associated control software. Writing control software in parallel with the mechanical and electronic design enabled testing of the exchanger to be carried out both during development and on final delivery.

3.2.3 Manufacture of Framework

Appendix 1 shows schematics of the SSL design. The framework and cradle is predominately made from carbon fibre, but uses aluminium to connect various parts together. The carbon fibre structure fulfils the strength requirements whilst not exceeding the 10 kg maximum weight, and is a non-magnetic inert material. The top and bottom stations use four jacks, driven by stepper motors, to accurately position the stations in the vertical plane. Each station has four limit switches two of which limit the travel of the stations and the other two act as fail safe cut off switches.

3.2.4 Control Electronics

The weight exchanger control electronics are operated by an IBM compatible PC running Windows '95. The stepper motors are driven via two 3.5 amp bipolar chopper drive units. The power supply is 24 volt DC. The stepper drive board and switch control lines are interfaced with the PC using a 40 channel I/O card. The I/O card has two controllable output clocks which provide the timing for the stepper drive board.

3.2.5 Control Software

The control software is written in Visual Basic version 5.0. The software is designed to exchange the weights within a 1 kilogram window at 50 kg load hence minimising the effect of hysteresis in the system. The data is saved as an output file and can be analysed within Microsoft Excel or any other spreadsheet package. The program has several variable test parameters which allows the operator to customise the operation of the exchanger for different applications.

4 ASSESSMENT OF THE MODIFIED BALANCE

4.1 Centralising Weights

Using a manual hydraulic forklift, weights can be placed on both stations with the operator using judgement to get the weight as central as possible. Then by lowering and raising the stations one at a time the level-matic pan and swinging cradle can be used to centralise the weights on the two stations. The bottom station, due to its longer leverage distance from the fulcrum only takes a couple of applications before it finds its central position. The top station, due to its closer proximity to the fulcrum, requires a larger moment to swing and may be limited by friction in the level-matic pan when nearing its true centre.

4.2 Comparison of Weighings

The automatic weight exchanger was assembled in the bullion balance enclosure in NPL's building 17 and assessed as a comparator with two standard 50 kg knob weights, both in automatic mode (using the computer software to exchange the stations with a constant load and collect the data) and in manual mode (applying and removing the weights allowing the balance to return to zero between exchanges with the operator recording the data). The weights were exchanged ten times and an

average reading, standard deviation, and maximum difference calculated. The average difference was then corrected for the difference in the centre of gravity between the two stations and compared with the difference between the reference values of the two weights, giving a value for the accuracy of the comparison. The weights were then swapped between the top and bottom stations, to determine whether there is any difference between the two stations. Table 5 shows the results obtained compared with those previously obtained using the balance with the level-matic pan.

Load		Level-matic Pan	Manual Exchange	Automatic Exchange
50 kg Comparison	Std dev (mg)	47	16	15
	Max diff (mg)	140	45	40
	Error (mg)	58	2	2
50 kg Comparison (weights swapped)	Std dev (mg)		7	8
	Max diff (mg)		20	30
	Error (mg)		7	7

Table 5: Repeatability assessment of the weight exchanging mechanism

The 50 kg comparisons using the exchanger and “level-matic” pan gave more repeatable results than using the level-matic pan on its own. Using the exchanger also gave more accurate results in determining the difference between the two weights. The differences between the results obtained using the exchanger manually and automatically were less significant, both giving similarly good repeatability and accuracy of weighing.

4.3 Conclusion

The introduction of an automatic weight exchanger has significantly improved the accuracy of weighing on the balance. However, there is no significant difference between using the exchanger manually or automatically. This implies that the hysteresis of the balance is not as significant as first assumed and that finding a way of exchanging the weights so that they are always placed on the balance in the same position is the most critical factor.

5 PROBLEMS ARISING

A problem which has been found with the weight exchanger is the positioning of the weight on the top station. It is not always possible to find the true central position for the weight on the top station due to its short leverage distance from the fulcrum and the friction which it has to overcome in the system. It may only be a small off-centre error which was unnoticed when using the exchanger manually (see results in Table 5). However when the balance is used as an automatic exchanger the small off-centre error affects the positioning of the weight on the bottom station (longer

leverage distance). This problem is accentuated further as the weights are repeatedly exchanged, until the bottom station begins to foul the cradle against the framework thus affecting the balance readings. Setting the balance up to do ten automatic weight exchanges has proved to be troublesome, with about only one run in five making it through the full ten exchanges. The system has generally been fouling after eight exchanges, but again varies depending on how well centred the top station weight is to begin with. This problem is not crucial as the exchanger can still be used manually and gives good results, however it is a nuisance as the system cannot be set up and left to collect data automatically with any reliability as it was designed to. Two solutions to this problem may be written into the software. The first solution would be to set up a temporary pause in the data collection after five exchanges so the exchanger could then independently re-centre the weights. This would have to be repeated if more than ten exchanges were required as the problem of getting the top station perfectly centred would never be overcome. A second solution would be to automatically exchange the weights without keeping a constant load on the balance (as performed in the manual exchanges without any sacrifice to the results).

This problem could have been reduced in the mechanical design of the weight exchanger by incorporating two stations below the balance instead of one above and one below. This would have overcome the short leverage problem and always found the true centre for both weight stations. But it would provide only limited access to both weighing stations (see section 3.2.1).

6 FURTHER WORK

The problem of the weights moving during an automatic weighing (described in section 5) needs to be addressed. This can be dealt with in the software, and again a solution is described in section 5.

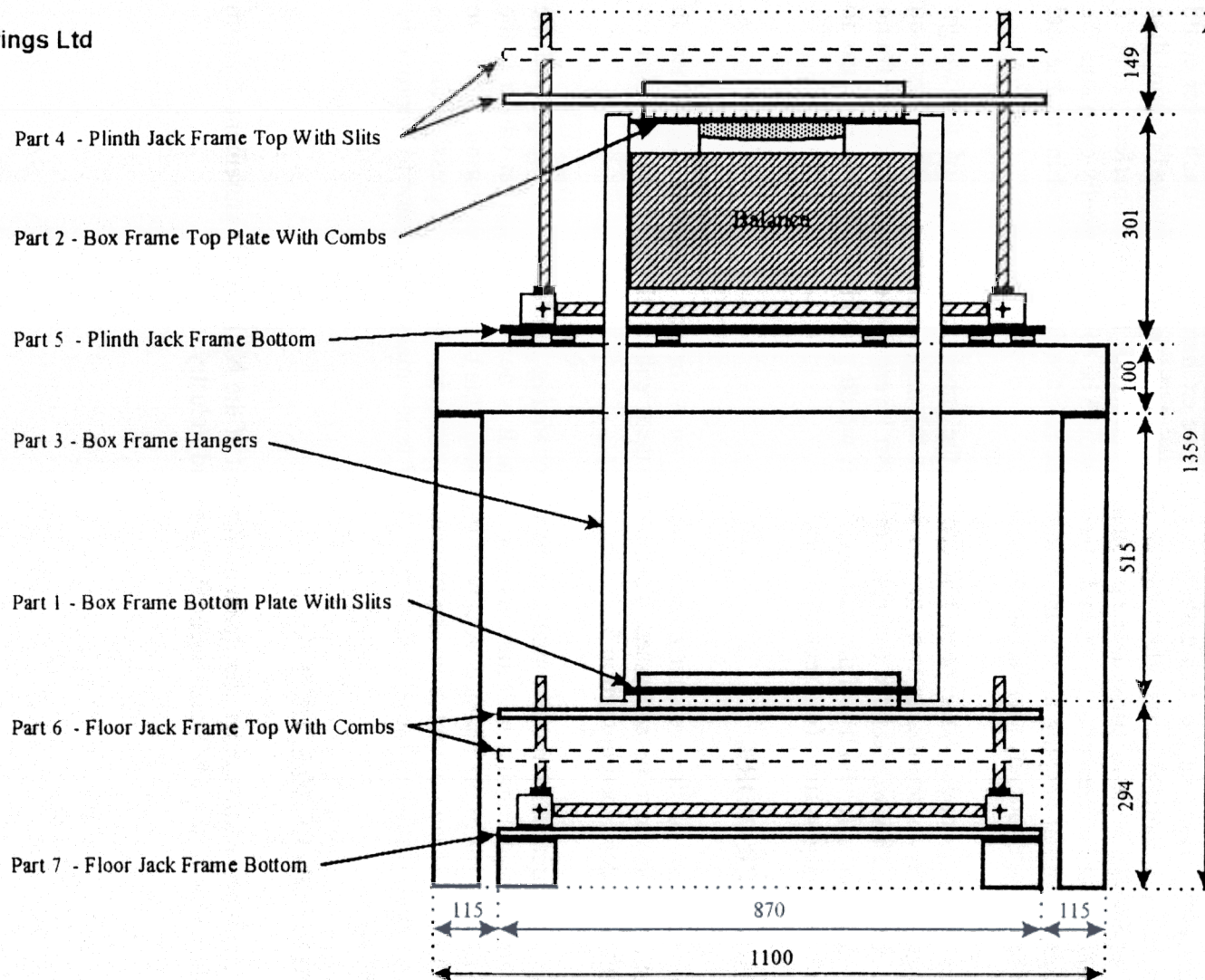
The introduction of the automatic weight exchanging mechanism has improved the balance's repeatability to within its resolution. It is now the resolution which is the limiting factor of the balance. A way of improving the balance's resolution may be to read the analogue output from the measuring element, and apply regression analysis techniques similar to those used by NPL's 2.7 tonne mass comparator to improve its resolution.

7 ACKNOWLEDGEMENT

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SSL

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