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DEVELOPMENT OF A LARGE MASS WEIGHT EXCHANGER

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Abstract: Top pan electronic comparators, which are widely used in National Measurement Institutes and mass calibration laboratories, for large mass calibration, inherently suffer from eccentricity and hysteresis. NPL has taken a commercial 60 kg comparator and designed an automatic weight exchanging mechanism to overcome these problems. This has been achieved by using a self centring scalepan with two weighing stations and exchanging between these two stations whilst maintaining a constant load on the comparator.

This paper outlines the initial assessment of the commercial comparator, describes the conceptual design of the weight exchanger, and comments on the improved performance observed from the comparator with the exchanger. The paper also discusses the work currently in progress on a second generation weight exchanger, scaling the project up to 500 kg, incorporating modifications to overcome the problems found in the 50 kg weight exchanger.

Keywords: Large Mass, Weight Exchanger, Mass Comparator

1 INTRODUCTION

NPL's Mass Section maintains the UK mass scale and provides traceability to the UK's official copy of the International Prototype of the Kilogram from 1 mg up to 2.7 tonnes. The weakest link in this traceability chain is the Bullion Balance, a 310 kg capacity equal arm two pan balance manufactured by Oertling, which has a resolution of 1 mg but is limited by its poor repeatability. The balance has been in use at NPL for over 30 years during which time several modifications have been made to it with no significant improvement to its performance [1].

NPL undertook a programme of work to design an automatic weight exchanger for a commercial 60 kg top pan comparator. If this work proved to be successful it was hoped to scale the work up to 500 kg and thus supersede the Bullion Balance.

2 ASSESSMENT OF A COMMERCIAL COMPARATOR

A Sartorius C60000S top pan comparator (60 kg capacity, 10 mg resolution) was evaluated to assess its suitability for use with an automatic weight exchange mechanism. The comparator was tested for repeatability, eccentricity and hysteresis.

The repeatability of loading was assessed by manually removing and replacing a weight on the comparator ten times. Readings of the zero as well as the load were taken, so any drift could be measured and eliminated. The repeatability check was initially performed at 50 kg and 10 kg loads. The spread of results and standard deviation of these repeatability tests gave poor results especially at the heavier loads. When used as a comparator, performing a series of ABA weighings with two 50 kg weights, it began to give unstable readings after a few comparisons.

The eccentricity of the comparator was checked by placing a 20 kg weight at front, back, left, right and central positions on the pan (concentric circles were marked on the pan to aid the positioning of weights). The dependency of distance from centre was also studied. The results of these tests showed that the comparator was extremely sensitive to off-centre loading. The degree of eccentricity predictably showed that the further a weight is moved from the centre the bigger the difference becomes, and the effect was found to be more pronounced in certain directions.

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

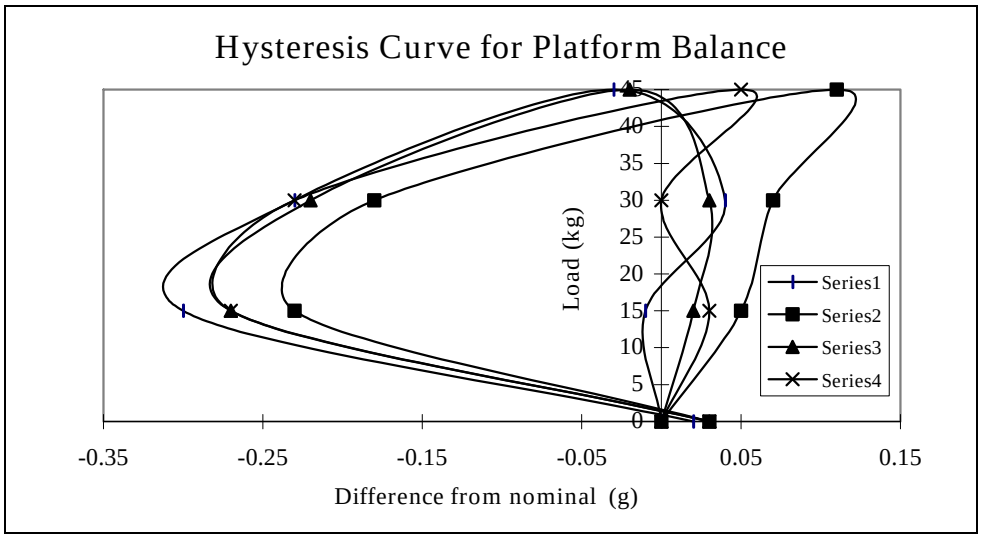

Figure 1. Plot of results of hysteresis assessment

Figure 1 illustrates the hysteresis exhibited by the comparator. The y-axis represents the actual load applied to the comparator and the plotted points represent the deviation from this value (indicated on the x-axis). 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 comparator readings obtained from increasing and decreasing the applied load. The maximum hysteresis error was calculated to be approximately 0.001%, a mass equivalence of about 500 mg in 50 kg.

3 MODIFICATION OF COMPARATOR

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

3.1 Self Centring Pan

A Mettler-Toledo level-matic centring pan was purchased. This pan consists of a race of ball bearings held between a pair of curved 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 comparator was assessed for repeatability using this device and compared with the results previously obtained. The introduction of the level-matic pan improved the repeatability of the comparator by more than a factor of two, but it was observed that care still had to be taken when positioning the weight.

3 2 Weight Exchanger

On analysis of the assessment data the two major problems with the comparator which needed to be addressed in the design of an automatic weight exchanging system were: placing the weights centrally and repeatedly on the pan (which to some extent has been overcome by the level-matic pan), the effect of keeping a constant load on the comparator when exchanging the weights in order to eliminate hysteresis.

3.2.1 Conceptual Design

A conceptual design for a weight exchanger had to fulfil the following functional requirements:

- The framework and scalepan had to provide a structure strong enough to support 50 kg without significant flexing.
- The scalepan itself could weigh no more than 10 kg. (This 10 kg limit is necessary as the comparator has 60 kg capacity and the scalepan will be in constant contact with the weighing pan so reducing the usable range to 50 kg).
- The material used had to be non-magnetic and non-abrasive, since it would come into contact with mass standards.

- The weight exchanger would be required to calibrate force machine deadweights, which are not of regular sizes or dimensions, therefore the top station had to be an open platform large enough to accommodate these types of weights. The bottom station could be more restricted in access provided it could accommodate a standard OIML[2] shaped 50 kg knob weight.

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

Figure 2. Weight exchanger and control equipment

Figure 2 shows the completed weight exchanger. The framework and scalepan is predominately made from carbon fibre, but uses aluminium to connect various parts together. The carbon fibre structure fulfils the strength and rigidity requirements whilst not exceeding the 10 kg maximum weight, and is an inert non-magnetic 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 while the other two act as fail-safe cut off switches.

3.2.2 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.

3.2.3 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 COMPARATOR

The automatic weight exchanger was 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 and allowing the comparator 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 error in the comparison. The weights were then swapped between the top and bottom stations, to determine whether there was any systematic difference between the two stations. Table 1 shows the results obtained compared with those previously obtained using the comparator with the level-matic pan.

Table 1. Repeatability assessment of the weight exchanging mechanism

Load		Level-Matic Results	Manual Exchange	Automatic Exchange
50 kg Comparison	Std dev (mg)	47	7	8
	Max diff (mg)	140	20	30
	Error (mg)	58	7	7

The 50 kg comparisons using the exchanger and centring pan gave more repeatable results than using the centring pan on its own. Using the exchanger also gave more accurate results (smaller error) 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.

4.1 Conclusion

The development of an automatic weight exchange mechanism on a 50 kg top pan comparator has significantly improved the repeatability and accuracy of weighing on the comparator. However, there is no significant difference between using the exchanger manually or automatically (maintaining a constant load). This implies that the hysteresis of the comparator is not a significant factor when being used as a comparator and that finding a way of exchanging the weights so that they are always placed on the comparator in the same position is the most critical factor in obtaining repeatable and accurate results.

5 FURTHER WORK

The results from this work, have shown that by taking a commercial top pan comparator (with poor repeatability and inherent eccentricity and hysteresis) and incorporating an automatic weight exchange mechanism it is possible to get the comparator to perform to within its resolution. It was therefore decided to proceed with the development of a 500 kg version of this weight exchanger.

5.1 500 kg Comparator

The comparator which is to be used is a Mettler-Toledo KC500-1. Mettler-Toledo have specially developed a new measuring cell and modified the comparator to give a 10 mg resolution instead of the standard 100 mg. Depending on the repeatability of the comparator with a weight exchange mechanism this will potentially give the required resolution to supersede the Bullion Balance and calibrate weights from 100 kg to 500 kg.

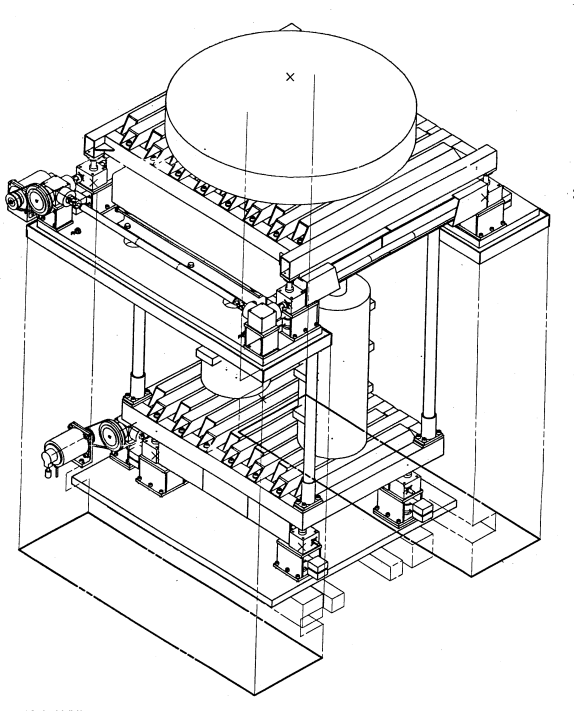

Figure 3. Schematic of 500 kg Weight Exchanger

5.2 Weight Exchanger

Figure 3 shows an isometric view of the proposed new 500 kg weight exchanger which will work on the same principal as the 50 kg version. A self centring scalepan is suspended from the comparator. There are two weighing positions one above and one below the comparator. The weights are exchanged on and off the scalepan by two exchanging stations via a series of fins and spaces. The exchanging stations are fixed in position, a feature which is not present in 50 kg version. This should overcome the fact that 50 kg weight exchanger can move out of alignment after some time in use. Having the stations positively located means that the initial set up should be the only time the comparator, scalepan and exchanging stations need to be aligned.

ACKNOWLEDGEMENT

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