An assessment of commercial mass comparators for the effects of magnetic and magnetically susceptible weights

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ABSTRACT

An investigation into the effect of magnetic weights on the performance of commercial mass comparators has been undertaken. The sensitivity of six comparators has been assessed using both magnetic and magnetically susceptible weights. Using a calibrated gaussmeter the balances were initially assessed for magnetic field strength, both in the weighing chamber and around the balance case, and checked for magnetic components. Further tests were performed using magnetised weights placed both directly on the weighing pan and spaced 117 mm above it. The results of these tests were used to assess the potential errors involved in the calibration of weakly and strongly magnetic weights. Finally magnets of various strengths were introduced into the proximity of the balance to assess the effect of stray magnetic fields on the balance readings. The results for the calibration of a magnetically susceptible kilogram weight on NPL's kilogram mass comparators are also summarised.

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1. INTRODUCTION

The interaction between weights and the balances on which they are used is a complicated issue with a number of aspects. A weight which has become magnetised may interact with parts of the balance which are magnetic or magnetically susceptible (often incorporated into the sensing element of the balance) and influence the balance reading, thus resulting in an inaccurate measurement. Similarly a weight of a magnetically permeable material will influence any magnetic fields associated with the balance and will not only affect the balance reading but may itself become magnetised. Thus the interaction between balance and weights works both ways and applies to magnetised and magnetically susceptible components and weights.

An investigation into the interaction between magnetic and magnetically susceptible weights and NPL Mass Section's commercial mass comparators has been undertaken. The balances were initially assessed for magnetic field strength both in the weighing chamber and around the balance case. Further tests were performed using weakly and strongly magnetic weights to assess the potential errors involved in their calibration. Finally magnets of various strengths were introduced into the proximity of the balance to assess the effect of stray magnetic fields on the balance readings. The results for the calibration of a magnetically susceptible kilogram weight on NPL's kilogram mass comparators are also summarised.

2. MEASUREMENTS

The Mass Section balances which were assessed as part of this investigation were those with capacity 1 kilogram or less and resolution of 0.1 milligram or better. The six balances tested are listed in Table 1 together with their capacities and resolutions.

Balance Model	Capacity	Resolution
Mettler HK1000MC	1000 g	0.001 mg
Sartorius C1000S	1000 g	0.001 mg
Mettler AT400	400 g	0.1 mg
Mettler AT201	205 g	0.01 mg
Mettler AT20	21 g	0.002 mg
Sartorius C5S	5 g	0.000 1 mg

Table 1: Capacity and resolution of balances tested

2.1 Assessment of balances for magnetic components and stray magnetic fields

For each balance a calibrated Hirst type GM04 (Hall probe) gaussmeter [1] was used to measure magnetic field strength inside the weighing chamber and around the balance. Before use the meter was zeroed using the shield provided. The background reading, due to the Earth's magnetic field was approximately 30 µT. The maximum field strengths measured around the balances are given in Table 2.

Balance Model	Measured field strength	Position
Mettler HK1000MC	No change	
Sartorius C1000S	600 µT	Bolts on top plate of base
Mettler AT400	No change	
Mettler AT201	No change	
Mettler AT20	No change	
Sartorius C5S	200 µT	Top of balance case
"	500 µT	Power supply at back of balance

Table 2: Measured field strength around the balances tested.

2.2 Measurement of a weakly magnetic weight

A magnetic weight, of approximate mass 10 grams and with maximum magnetic field strength 600 µT, was used to assess the sensitivity of the top pan balances to weakly magnetic weights. The weight strongly attracted the compass needle used within the Section to assess the suitability of test weights for calibration and had a permeability of greater than 2.5 when checked with the Severn bridge permeability meter. Both the field strength and permeability values of this weight were much higher than would normally be accepted for a test weight submitted by a customer for calibration.

The weight was initially measured when placed directly the pan and then at a distance of 117 mm above the pan using the aluminium spacing tube from the magnetic permeability rig [2] as illustrated in figure 1. The difference between the two measured values for the weight gives an indication of the sensitivity of the balance to magnetic weights and an idea of the potential uncertainties associated with the calibration of such weights.

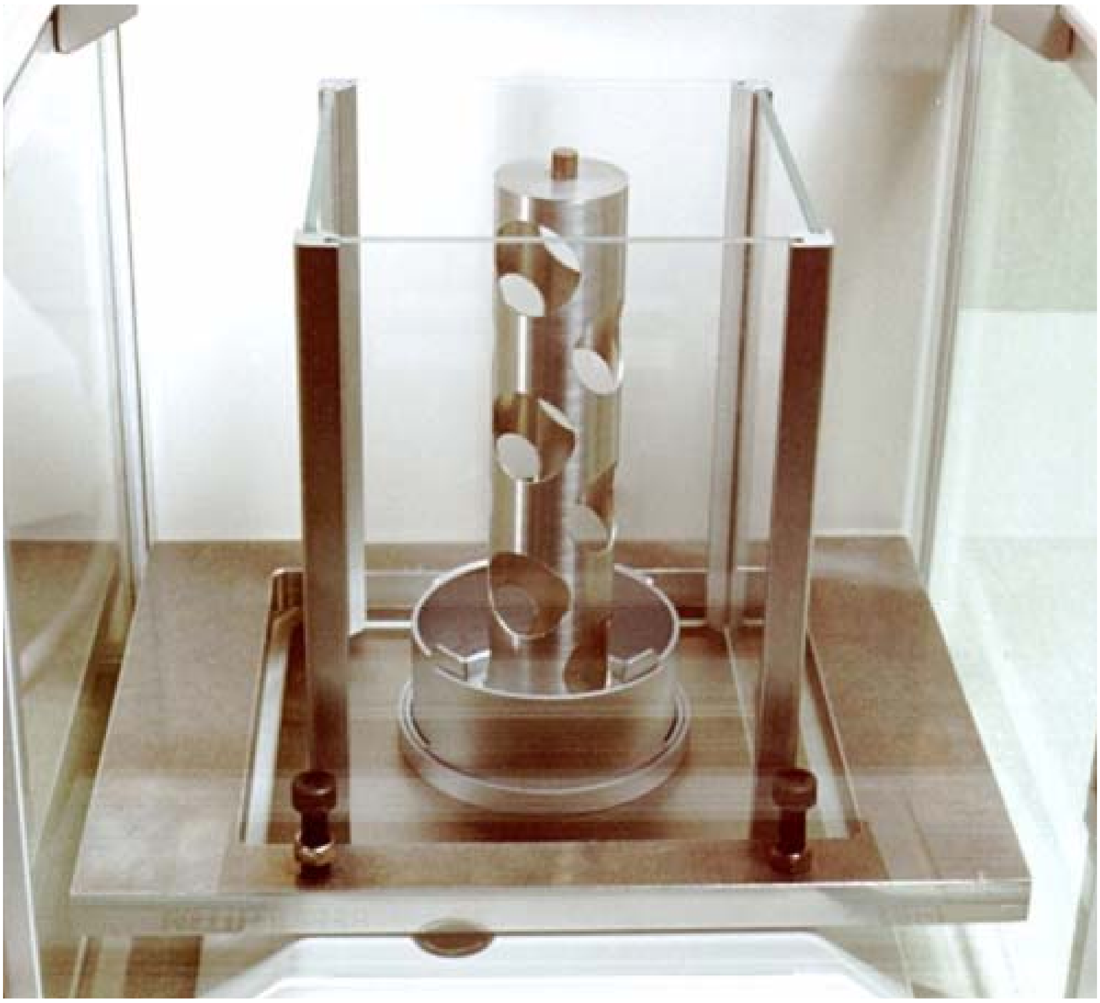

Figure 1: Weight on top of aluminium spacer (Mettler AT20 balance)

Table 3 gives the measured difference between the balance reading with the weight in the two positions described. The results represent the averages of between 4 and 12 readings taken for each balance.

Balance model	Measured mass difference (on pan - 117mm above pan) (µg)
Mettler AT400	-100
Mettler AT201	-42
Mettler AT20	-50

Table 3: Balance sensitivity to weakly magnetic weight

2.3 Balance sensitivity to a permanent magnet

A permanent magnet of approximate field strength 60 mT was weighed in contact with the balance pan and at a distance of 117 mm above the pan as described in Section 2.2. The results of the test are given in Table 4. Each result represents the average of 8 readings taken for each balance.

Balance model	Measured mass difference (on pan - 117mm above pan) (µg)
Mettler AT400	+875
Mettler AT201	-1065
Mettler AT20	+472

Table 4: Balance sensitivity to permanent magnet

2.4 Balance sensitivity to magnetic fields

Permanent magnets of 60, 90, 200 and 300 mT field strength were moved around the balances and the maximum changes in the balance reading, together with the magnet's position, were recorded. Table 5 gives the results of this test.

Balance model	Field strength of magnet (mT)	Maximum change in balance reading (mg)	Position of magnet
Mettler AT400	60	-50	Corners of pan
	90	-150	"
	200	-2 000	"
	300	-250	"
Mettler AT201	60	-50	Corners of pan
	90	-150	"
	200	-1 200	"
	300	-400	"
Mettler AT20	60	-0.8	Pan
	300	-7.0	"
Sartorius C5S	300	No change	Outside weighing chamber

Table 5: Balance sensitivity to proximity of permanent magnet

2.5 Balance sensitivity to Edale analogue temperature probe

The Edale thermistor No. 3776 has an analogue display using a moving coil meter. This device is used within the Section to measure temperature inside the balance weighing chamber during mass calibrations. It has been noted that the proximity of the meter to the balance affects the balance reading. In this test the Edale meter was placed next to the balance case and the change in the balance reading was noted. Table 6 gives the results of this test. The sign of the balance change depended on the orientation of the Edale meter.

Balance model	Change in balance reading (μg)
Mettler AT400	300
Mettler AT201	600
Mettler AT20	30

Table 6: Balance sensitivity to proximity of Edale meter

For all three balances the influence of the Edale was undetectable at distances above 15 cm from the balance case.

2.6 Measurement of a magnetically permeable weight on kilogram comparators

A stainless steel kilogram weight with a high magnetic susceptibility, submitted for calibration, was weighed on both the Mettler HK1000MC and Sartorius C1000S kilogram mass comparators. When received the weight was found to be magnetic, with an average field strength of approximately 2 mT, and was de-gaussed. This essentially removed any residual magnetism in the weight, while the weight remained magnetically susceptible. The susceptibility of the weight was measured using a "Davis" susceptibility meter manufactured at NPL [2] and was found to be of the order of 0.5; the OIML recommendation for mass standards [3] gives limits of 0.01 and 0.03 for Class E_1 and Class E_2 weights respectively. The kilogram weight was calibrated on both kilogram comparators in both its normal orientation (base downwards) and inverted. The weight was also calibrated on the NPL Precision Balance [4], a purely mechanical balance manufactured from entirely non-magnetic materials, to give a mass value for the weight theoretically independent of its magnetic susceptibility. Table 7 summarises the results obtained for the calibration of this weight on the three balances used.

Balance	Weight orientation	Measured mass value (1kg + µg)	Diff. relative to precision balance (µg)
Sartorius C1000S	Upright	926	+137
	Inverted	956	+167
Mettler HK1000MC	Upright	931	+142
	Inverted	979	+190
NPL Precision balance	Upright	789	-

Table 7: Calibration of magnetically susceptible weight using 1 kilogram comparators

3. CONCLUSIONS

The initial assessment of the balances for magnetic field strength showed only minor magnetic fields or magnetised components, and these were well away from their weighing chambers. This suggests that all the balances should be broadly unaffected by magnetically susceptible weights and should not magnetise such weights when they are weighed on these balances.

The calibration of a weakly magnetic weight on the three top pan balances showed that these balances are reasonably insensitive to such weights. The Mettler AT20 showed the largest proportional change in the balance reading with the AT400 and AT201 giving changes within the uncertainty of measurement associated with the balance. It should be noted that the field strength of the weight used in this test was much higher than would be accepted for a weight submitted for calibration.

As expected the three top pan balances showed much greater sensitivity to highly magnetic weights (field strength 60 mT). The Mettler AT201 showed the largest change in balance reading when the weight was moved away from the pan. The change also had the opposite sign to the other balances suggesting that the orientation of the permanent magnet in the sensing element of the balance is inverted relative to the AT20 and AT400.

Apart from the C5S all balances showed high sensitivity to moving magnetic fields, with the AT400 and AT201 showing similar sensitivity and the AT20 being less sensitive. The maximum change in balance reading was seen to be a function of the physical size of the magnet as well as its field strength. All the balances were much more sensitive to the moving magnetic field that they were to a stationary magnet of the same field strength (test 2.4 compared with test 2.3).

The three top pan balances were all affected by the proximity of the Edale analogue temperature probe display unit. The balances showed a constant offset due to the proximity of the meter, indicating that the meter should not be moved during the course of a calibration but should ideally be located at least 15 cm from the balance case where it has no effect on the balance reading.

The calibration of a magnetically susceptible weight on the three 1 kilogram mass comparators indicates that both the HK1000MC and C1000S are sensitive to such weights. While the assessment of the two balances for magnetic fields showed no significant results, the calibration of a magnetically susceptible weight on these balances is, in fact, a much more sensitive test given that the resolution of both balances is 1 part in 10^9. Given that the measurement made on the NPL Precision Balance represents a definitive mass difference independent of magnetic effects the C1000S and HK1000MC show errors of between 137 and 190 µg in the measured mass value of the test weight. The orientation of the weight also effected its measured value suggesting either some residual magnetism or a non-uniformity in the magnetic susceptibility of the material.

4. ACKNOWLEDGEMENTS

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