

The Calibration of Force Transducers 'On-the-Fly'

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September 2002

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Abstract

Present standards governing the calibration of force measuring devices stipulate that the deflections are taken under equilibrium conditions, where the calibrating force is static. Instead, if deflections were to be measured while the calibrating force swept the load range of the device, considerable savings in calibration time would accrue. Given the number of these devices in commercial use, significant benefits to the national economy would follow. Moreover, this quasi-static calibration method would approximate the manner in which force transducers are used. This report details an investigation into the possibility of calibrating force transducers ‘On-the-Fly’, evaluating the impact of this quick and economic approach on the overall measurement uncertainty. Results indicate that a 20 kN Class 00 force measuring device calibrated to BS EN ISO 376:2002 can achieve similar uncertainties at incremental loading rates up to 100 N/s. By quantifying and closely controlling the measurement uncertainty, a completely new Standard covering the influence of non-constant load could be developed.

The work described was carried out under Deliverable 2.1.9 of the National Measurement System’s Mass Programme 1999-2002, funded by the Department of Trade and Industry.

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ISSN 1369-6785

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Approved on behalf of Managing Director, NPL,
by Dr Roy Preston, authorised by Head of Centre for Mechanical and Acoustical Metrology

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The Calibration of Force Transducers ‘On-the-Fly’

1. Background

1.1 Introduction

Traditionally, load cells have been calibrated traceably to National Standards using a step-wise methodology (e.g. BS EN ISO 376:2002). However, this does not reflect the manner in which most load cells are used in practice. The resulting poor uncertainty can, for instance, oblige manufacturers and suppliers of weighed goods to over-fill their quotas in order to be certain of complying with trading standards legislation, which ultimately represents a net loss to the economy. A report [1] commissioned in fulfilment of a separate deliverable of the 1999-2002 Mass Programme, concluded “the force-related calibration market is around £9 million per year, which could grow by £3 million if dynamic calibration were widely implemented. Improvements in dynamic force measurements on the order of 1 % could lead to savings within the UK economy of between £1 billion and £2 billion per year”.

This report summarises the work carried out at NPL to investigate the calibration of load cells in a quasi-static manner, evaluating the impact of this quick and economic approach on the overall measurement uncertainty. If measurement uncertainty can be quantified and closely controlled, then a completely new Standard covering the influence of non-constant loading could be developed.

1.2 Existing Literature

The substantial body of work has been done on traceable dynamic force calibration, over a range of frequencies, and reported in the literature. PTB, in particular, have conducted many studies in this area. They found that the response of the force measuring device was significantly influenced by the interaction between it and the surrounding mechanical system [2]. These inertial effects lead to relative uncertainties of several percent, but with careful system design (especially in maximising force transducer stiffness) these could be reduced to a few tenths of a percent [3]. Later work by Kumme [4] using a dynamic force standard machine to perform intercomparisons between force transducers showed good comparisons were possible below 100 Hz, but at higher frequencies the effects of resonance and inertia can lead to errors exceeding 20 %.

1.3 Scope of this Work

The scope of the work reported here was limited to the investigation of calibrating force application rates of linear (c.f. sinusoidal) shape, and the effect on accuracy of sampling frequency.

1.4 Methodology

The simplest experimental arrangement is to load two force-measuring devices in series in a force standard machine in which the loading rate can be closely controlled. One device (hereafter called the ‘loading device’), in closed-loop feedback to the machine controller, provides the calibrating force; the second (hereafter called the ‘mimicking device’) mimics the device undergoing on-the-fly calibration. A ramping force signal is sent to the controller, and the outputs of both devices captured in real time by a PC. If the response of the two devices is characterised in a deadweight force standard machine (so that the creep in both load cells can be taken into account), the relative error between the two devices at various loading rates and sampling frequencies can be deduced. Here, creep C_n is defined by the expression:

$$C_n = r_n - r_{ref} \quad \text{Equation 1}$$

where r_{ref} is the reference deflection, taken as a point where the applied load can be considered to have stabilised, and r_n is n th deflection following the reference deflection. The deflection of the load cell at a given force is defined as the output at that force minus the output at zero force prior to the force application.

It was decided to explore the compressive part of the load envelope only, as this requires a simpler mechanical arrangement, and in any case, the findings were expected to be equally applicable to tensile working. Similarly, incremental loading only was explored, as this is the most commonly used calibration mode.

2. Static Characterisation

2.1 Equipment

The characterisation was performed in the NPL 20 kN deadweight force standard machine, shown in Figure 1. This machine was chosen as it has the best uncertainty in the lower working range of the load cells used in this investigation. The machine is capable of applying 0,5 kN force increments up to 5 kN, and then 1 kN increments up to the full capacity of 20 kN.



Figure 1 The 20 kN deadweight force standard machine

The deadweight machine incorporates earth contact circuitry. This detects any touch between the supported weight and the earth side of the load cell, including loading transients, which would constitute an increased uncertainty in the load applied. The earth contact warning lamp usually extinguishes several seconds after the full deadweight has been applied, signifying that the applied load has stabilised.

The NPL 30 kN hardness standard machine, used for the dynamic characterisation, incorporates a 45 kN capacity load cell made by Baldwin Lima Hamilton (BLH), which is fixed to the crosshead, and used for both force measurement and feedback/control. This was therefore designated the loading device. Settings of the loading device used are given in Table 1.

Manufacturer:	BLH
Model number:	LPT
Serial number:	61097
Capacity:	45 kN
Excitation:	10 V

Table 1 Loading device details

In order to match the mechanical characteristics of the loading device as closely as possible, as would be the case in commercial ‘On-the-Fly’ calibrations, a 50 kN transfer standard load cell made by Gassmann Theiss Messtechnik (GTM), was chosen as the mimicking device. Settings of the mimicking device used are given in Table 2.

Manufacturer:	GTM
Model number:	KTN-D
Serial number:	42139
Capacity:	50 kN
Excitation:	10 V

Table 2 Mimicking device details

2.2 Protocol

The loading device was positioned on the earth platen of the 20 kN deadweight machine, with a bearing pad and ball arrangement interposed between its upper face and the scalepan. The load cell was connected to a Hottinger Baldwin Messtechnik (HBM) DMP40 digital precision measuring amplifier. This instrument provides the energising voltage to the load cell, reads the output signal from the load cell, and displays the ratio between the two, usually expressed in mV/V. This ratio signal was passed to a laptop computer via an IEEE-488 link and captured in a Visual Basic® logging programme as an ASCII file. Settings of the DMP40 used are given in Table 3. All circuitry was powered up, and the apparatus left for several hours to reach thermal equilibrium. The load cell’s temperature was then measured. In order to bed all fittings and condition the load cell, three preloads were performed, holding at 20 kN for one minute, after five minutes at zero load. Zero load was taken to be the condition in which the scalepan is out of contact with the load cell, so that the load cell experiences only the weight of the ball/pad assembly.

After resting the load cell for 30 minutes at zero load (to allow for complete creep recovery), the deadweight characterisation was performed as follows. The DMP40 logging programme was started together with a stopwatch, and a deadweight of 2 kN applied. The time at which the earth contact light extinguished was recorded. This is the reference time, t_{ref} . After three minutes under load the

deadweight was removed, and logging continued for a further ten minutes, in order to characterise creep recovery. The deflection data was saved to disk in ASCII DAT file format.

The loading profiles above were repeated, incrementing the applied force by 2 kN, to a total load of 20 kN, as shown in Figure 2. At the end of the test the temperature of the load cell and fittings was recorded. The process was then repeated for the mimicking device.

Model number:	DMP40
Serial number:	050520005
Bridge supply:	10 V
Measuring range:	2.5 mV/V

Table 3 DMP40 settings

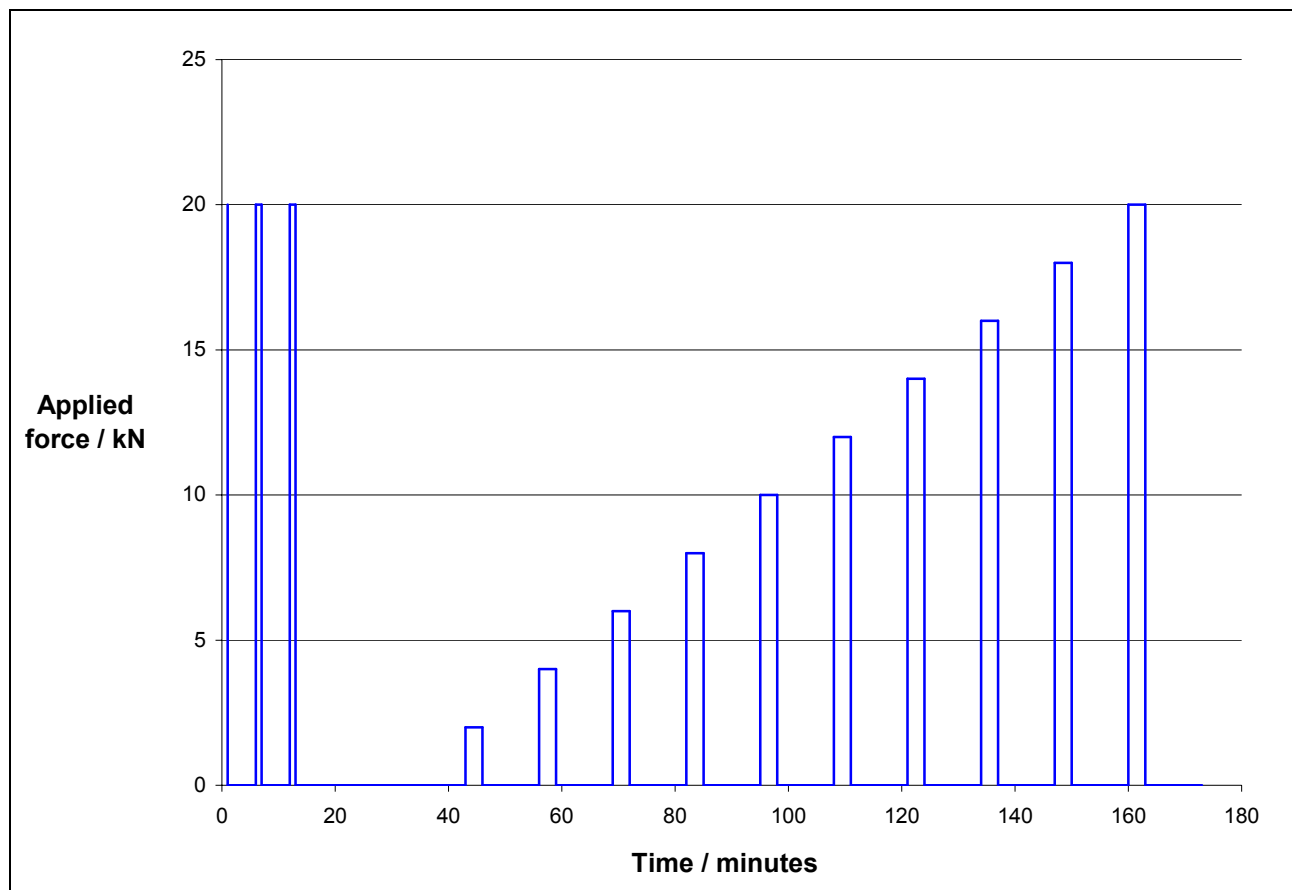


Figure 2 Applied load/time profile for the static characterisation

2.3 Mimicking Device Results

The deflection reading was taken 60 s after the time at which load was fully applied.

Applied load / kN	Deflection / mV/V
2	0.079 97
4	0.159 92
6	0.239 88
8	0.319 84
10	0.399 82
12	0.479 79
14	0.559 77
16	0.639 75
18	0.719 74
20	0.799 72

Table 4 Deflections of the mimicking device in the 20 kN deadweight machine

The creep and creep recovery profiles were calculated for each of the applied forces. The creep recovery profile has been inverted to aid comparison with the creep profile, as shown in Figure 3.

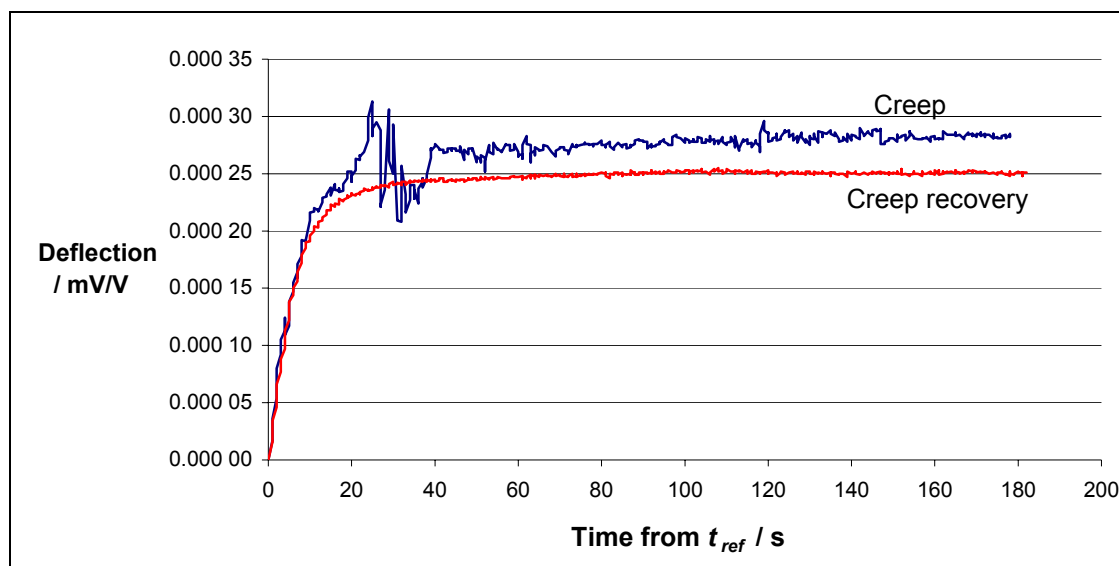


Figure 3 Creep and creep recovery of the mimicking device at an applied force of 20 kN

The creep and creep recovery profiles in Figure 3 are typical of those measured at other loads. The creep profile is noisier than the creep recovery profile because of the effect of the hanging weightstack

Figure 4 shows creep profiles at a range of applied loads.

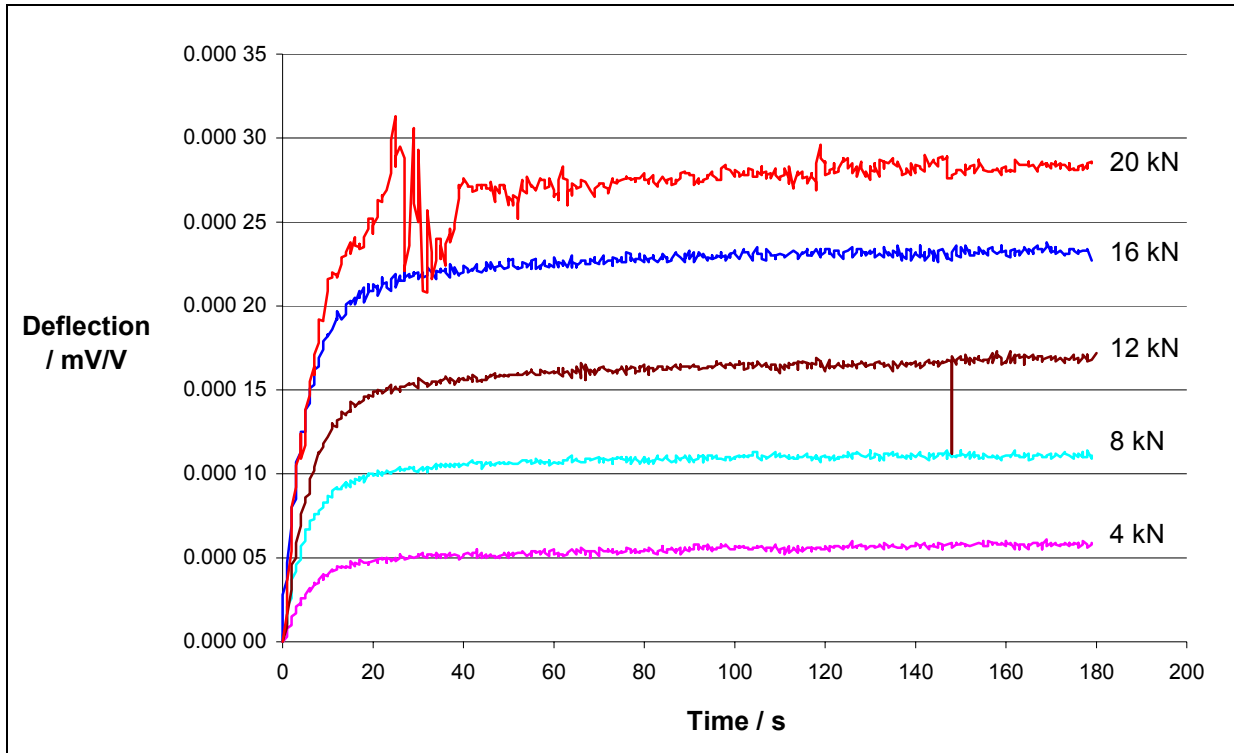


Figure 4 Creep profiles for the mimicking device at a range of applied forces

The magnitude of the creep is proportional to the applied load. Comparison of the deflection readings with those in Table 4 shows the creep to represent less than 400 ppm across the load range.

2.4 Loading Device Results

Figure 5 shows the creep and creep recovery of the loading device. As in Figure 3 the recovery profile has been inverted. It is noticeable that the creep response of the loading device is of the opposite sign to the mimicking device. The magnitude of the creep was approximately 140 ppm across the load range.

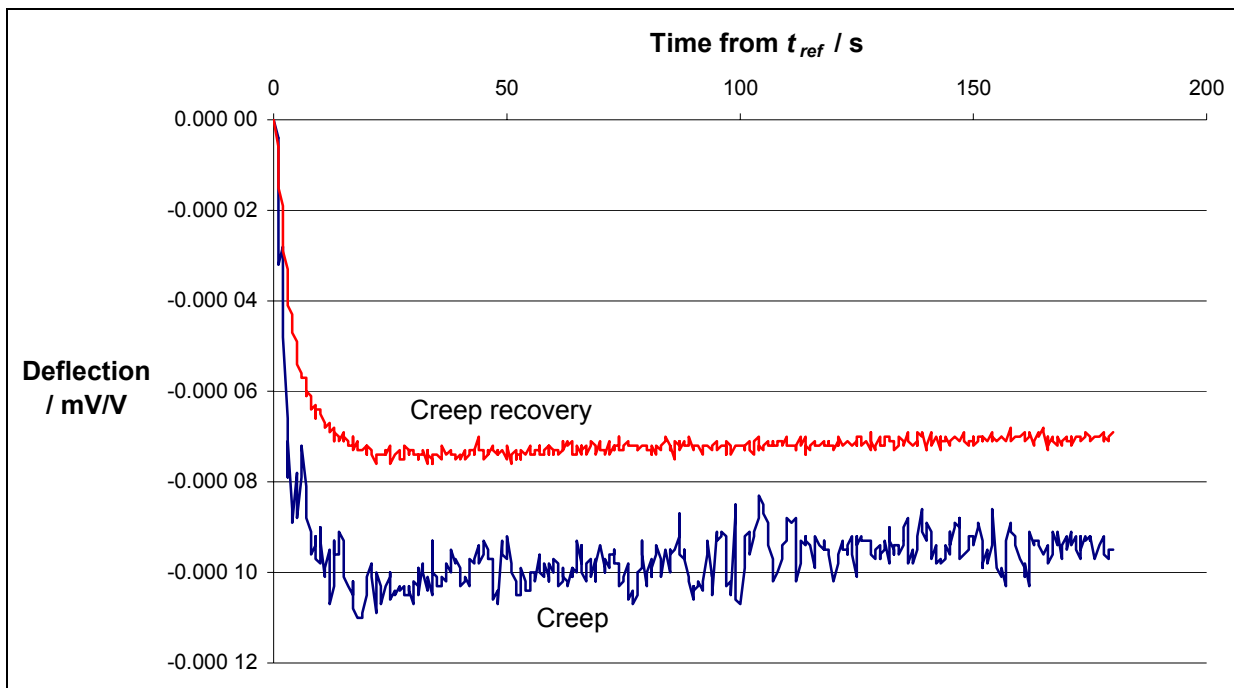


Figure 5 Creep and creep recovery of the loading device at an applied force of 20 kN

3. Dynamic Characterisation

3.1 Equipment

Initially, it had been planned to use the NPL 1 MN servo-hydraulic force standard machine for the investigation. This machine operates under PC control for the purpose of static calibration of force transducers. This is achieved using a bespoke static calibration programme written in the QuickBasic® language, and communicating with the servo-hydraulic machine via an OEM interface. Although performing static calibrations satisfactorily, this arrangement did not prove amenable to modification to dynamic working, owing to the hardware changes required at the interface, and the inherent inflexibility of a programme written in the MS-DOS environment. It was not possible to write a control programme in Visual Basic®, the programme of choice, since the control loop frequency achievable would not be high enough for this kind of test.

It was therefore decided to utilise the NPL 30 kN hardness standard machine (Figure 6) with suitable modifications. This is based on the servo-electric materials-testing machines made by Instron, having a loading frame capacity of 30 kN, and connected to a PC running Instron's Merlin® load profile software. This offered several advantages: the hardware added to the machine for the purposes of hardness testing could be readily bypassed, the software was specifically designed to run loading profiles of any shape, and the machine was already fully certificated for control and measurement of force, amongst other parameters. Furthermore, by capturing the outputs from the two load cells on two separate PCs, rather than on one programme running on one PC, this approach would be able to explore the mechanical boundaries of the technique, instead of the obvious software limitations of sampling frequency.



Figure 6 NPL 30 kN hardness standard machine

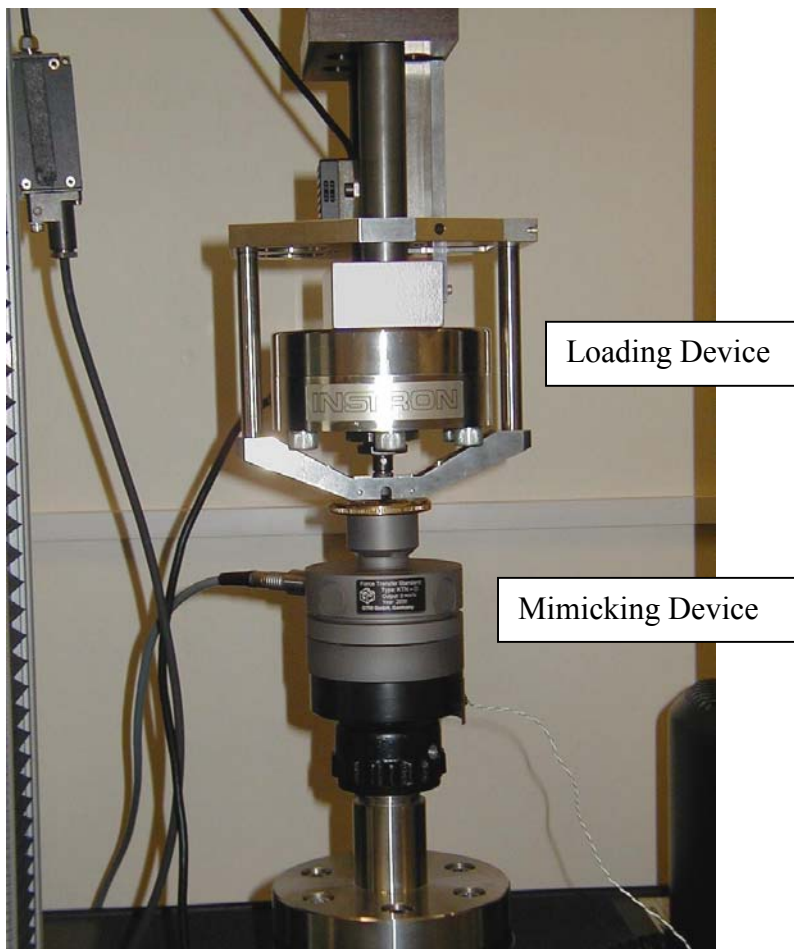


Figure 7 Arrangement of load cells in the 30 kN hardness standard machine

The mimicking device was located on the anvil of the frame, and a hardball and brass pad arrangement interposed between the two devices (Figure 7) to eliminate torsional and/or bending moment coupling between them. Both devices thus experienced the same pure vertical force acting vertically along their major axes, in accordance with their designs.

The loading device's excitation and signal conditioning was performed by an interface card within the Merlin system, and its output sent to Merlin for storing in a suitable ASCII file format. The same DMP40 as was used in the static characterisation was connected to the mimicking device using the same circuitry.

3.2 Protocol

Loads ramped linearly from 0 kN to 20 kN were explored in a series of runs, as follows. All apparatus was powered up, and then left to normalise at ambient temperature for several hours. The temperature of the load cells and fittings was measured to check they were within the customary $20\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ criterion. In order to bed all fittings and condition both devices, three preloads were performed, holding at 20 kN for one minute, after five minutes at zero load. At the zero load condition (with the ball and pad out of contact), the logging software for the mimicking device was started. A loading profile, earlier input into Merlin, was then commenced. This began with a dwell at zero load (to zero the loading device output), followed by an approach to ball/pad contact under position control. On contact, control passed to the loading device, and the ramp began. At 20 kN, the load was held for ten seconds, after which it was removed rapidly under position control. The purpose of this sudden unload was to provide a unique and precise time reference recorded by both devices which could subsequently be used to superimpose their output against time traces for the comparison of their respective deflections. It is reasonable to assume that a sudden removal of load provides such an event, as inertial effects are minimal owing to the high stiffness of the load chain.

Output from the loading device was sampled at 20 Hz, and stored subsequently stored by Merlin on the machine's hard drive. Output from the mimicking load cell was sampled at 8 Hz – 16 Hz and stored on the laptop.

Keeping all other properties of the loading profile unaltered, this procedure was repeated to explore a range of ramp rates from 50 N/s to 40 kN/s. At the end of the test the temperature of the load cells and fittings was recorded.

3.3 Results

Figure 8 shows the range of ramping rates that were used to apply a force of 20 kN to the mimicking device.

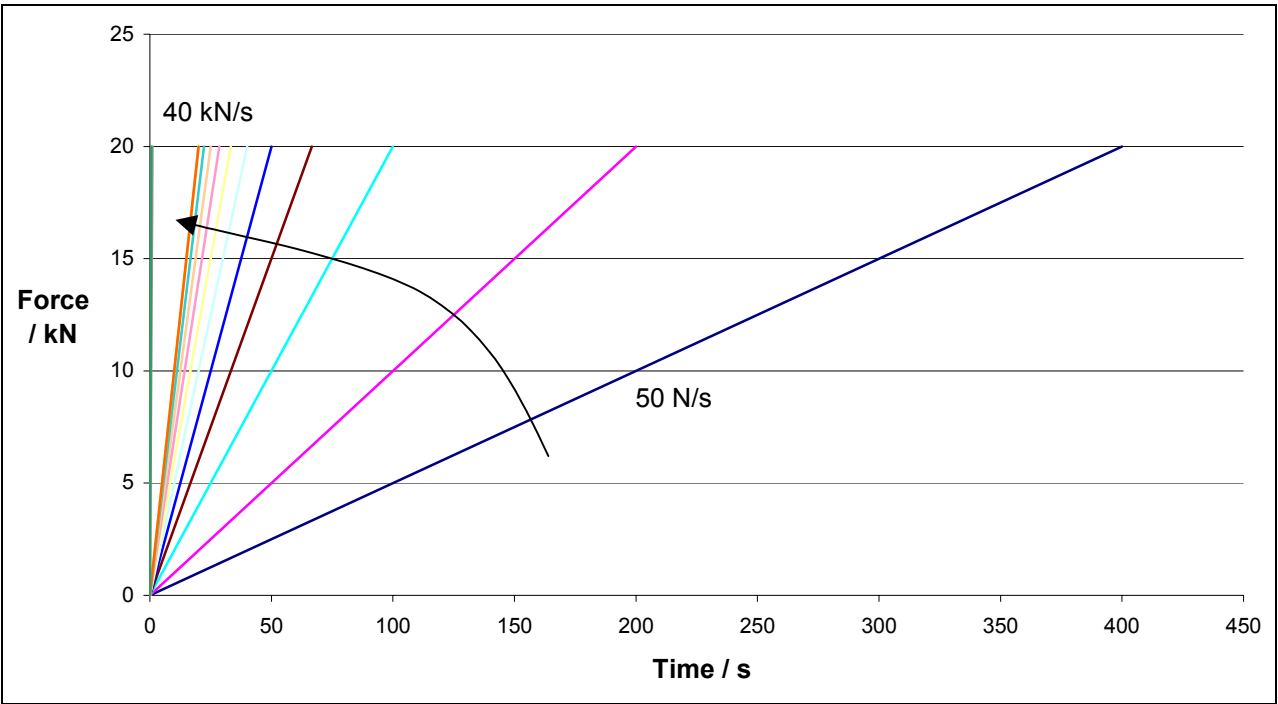


Figure 8 Range of ramp rates at which 20 kN was applied

From the data output, applied force against time profiles were obtained for each of the two devices, (see Figure 9).

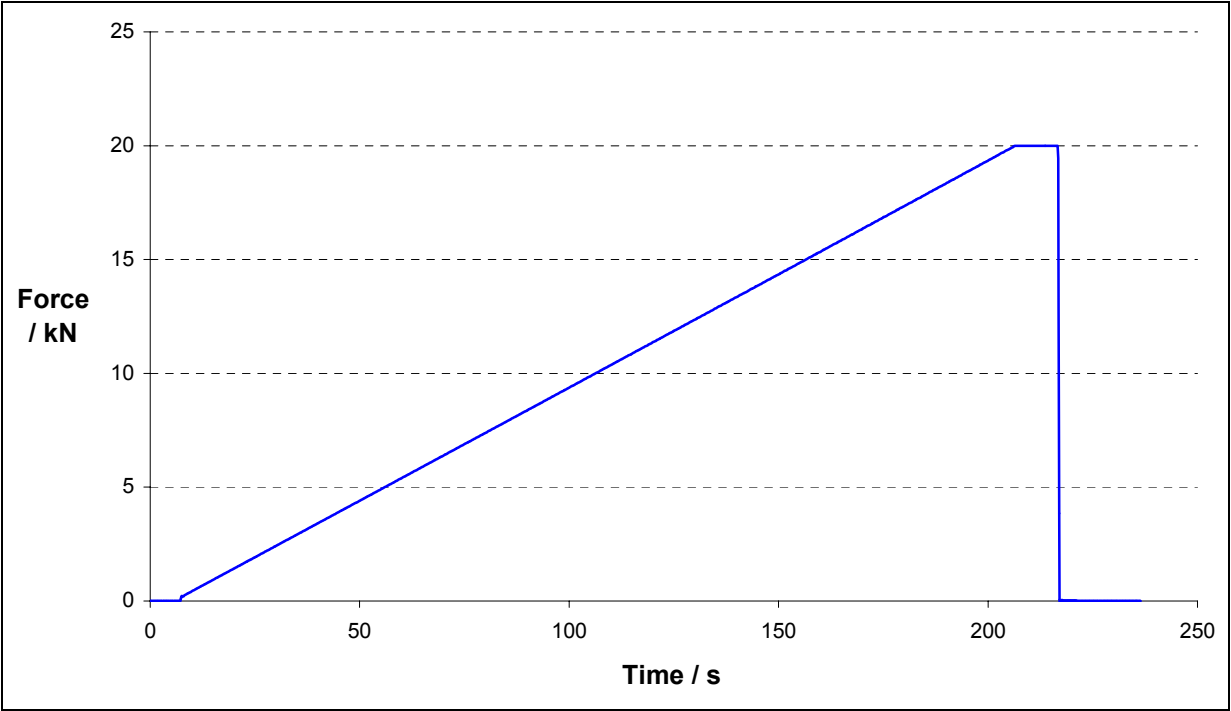


Figure 9 Applied force/time profile for the mimicking device at a 100 N/s ramp

The applied force/time profiles for the two devices were measured on different time axes. In order to analyse the response of the mimicking device to the applied force, as measured by the loading device, the two axes needed to be matched. This was achieved by matching the point at which the load was removed. The time axis of the mimicking load cell was offset accordingly to enable corresponding values to be compared from each profile. Through interpolation for a given output from the loading device the output from the mimicking device was calculated.

Table 5 shows the deflections of the mimicking device at a range of ramp rates from 100 N/s to 1 kN/s.

Ramp Rate		100 N/s	200 N/s	1 kN/s
Loading Device kN		Mimicking Device mV/V		
2		0.079 78	0.079 39	0.077 66
4		0.159 80	0.158 83	0.157 35
6		0.239 72	0.238 95	0.237 89
8		0.319 55	0.318 99	0.317 07
10		0.399 50	0.399 07	0.397 42
12		0.479 33	0.478 99	0.476 98
14		0.559 37	0.558 60	0.556 49
16		0.639 21	0.638 32	0.637 44
18		0.718 95	0.718 71	0.717 32
20		0.798 93	0.798 72	0.798 36
Sample rate / Hz	Mimicking device	16.63	16.22	16.16
	Loading device	20.54	20.48	20.51

Table 5 Effect of ramp rate: Deflections at different ramp rates

It was hoped that the upper limits of ramp rate could be explored. However a maximum sample rate of approximately 16 Hz imposed by the software measuring the output from the mimicking load cell meant that for ramp rates above 100 N/s significant errors were introduced. For this reason the region around 100 N/s was focussed on. In addition, time saving benefits for ramp rates in excess of 100 N/s were insignificant compared to those already made.

The effect of sample rate on the process was also explored and shown in Table 6.

Ramp Rate		100 N/s	100 N/s
Loading Device kN		Mimicking Device mV/V	
2		0.079 37	0.079 78
4		0.159 53	0.159 80
6		0.239 45	0.239 72
8		0.319 15	0.319 55
10		0.399 17	0.399 50
12		0.479 16	0.479 33
14		0.558 85	0.559 37
16		0.639 15	0.639 21
18		0.719 01	0.718 95
20		0.799 20	0.798 93
Sample rate / Hz	Mimicking device	8.76	16.63
	Loading device	20.33	20.54

Table 6 Effects of sample rate: Deflections at different sample rates

Table 7 gives the deflections of the mimicking device for three runs under near identical conditions (slight variation in sample rate) in order to give a measure of the repeatability of the dynamic characterisation. Problems with the sampling software meant that 8 Hz was the highest rate at which three runs were recorded.

Ramp Rate		100 N/s 01	100 N/s 02	100 N/s 03
Loading Device kN		Mimicking Device mV/V		
2		0.079 37	0.079 21	0.079 43
4		0.159 53	0.159 38	0.159 49
6		0.239 45	0.239 22	0.239 43
8		0.319 15	0.319 14	0.319 31
10		0.399 17	0.398 96	0.399 11
12		0.479 16	0.479 02	0.479 15
14		0.558 85	0.559 07	0.559 06
16		0.639 15	0.638 94	0.639 08
18		0.719 01	0.718 86	0.718 87
20		0.799 20	0.798 90	0.798 98
Sample rate / Hz	Mimicking device	8.76	8.76	8.57
	Loading device	20.33	20.59	20.39

Table 7 Repeatability: Deflections for three readings at the same ramp and sample rates

4. Analysis

To give a measure of the accuracy of the dynamic characterisation, readings were compared with the corresponding deadweight values, based on the assumption that the applied force as measured by the loading device, in the dynamic characterisation, corresponds to that from the 20 kN deadweight machine for the static characterisation.

Table 8 shows the difference in deflections between the static characterisation as given in Table 4 and the dynamic characterisation given in Table 6.

Ramp Rate		100 N/s	100 N/s
Loading Device kN		Mimicking Device mV/V	
2		0.000 59	0.000 18
4		0.000 39	0.000 12
6		0.000 43	0.000 16
8		0.000 69	0.000 29
10		0.000 65	0.000 32
12		0.000 63	0.000 46
14		0.000 93	0.000 40
16		0.000 60	0.000 53
18		0.000 72	0.000 78
20		0.000 51	0.000 79
Sample rate / Hz	Mimicking device	8.76	16.63
	Loading device	20.33	20.54

Table 8 Difference in deflections between dynamic and static characterisations at different sample rates

The differences from Table 8 were plotted in terms of ppm deviation from the static characterisation values in Table 4. This is shown in Figure 10.

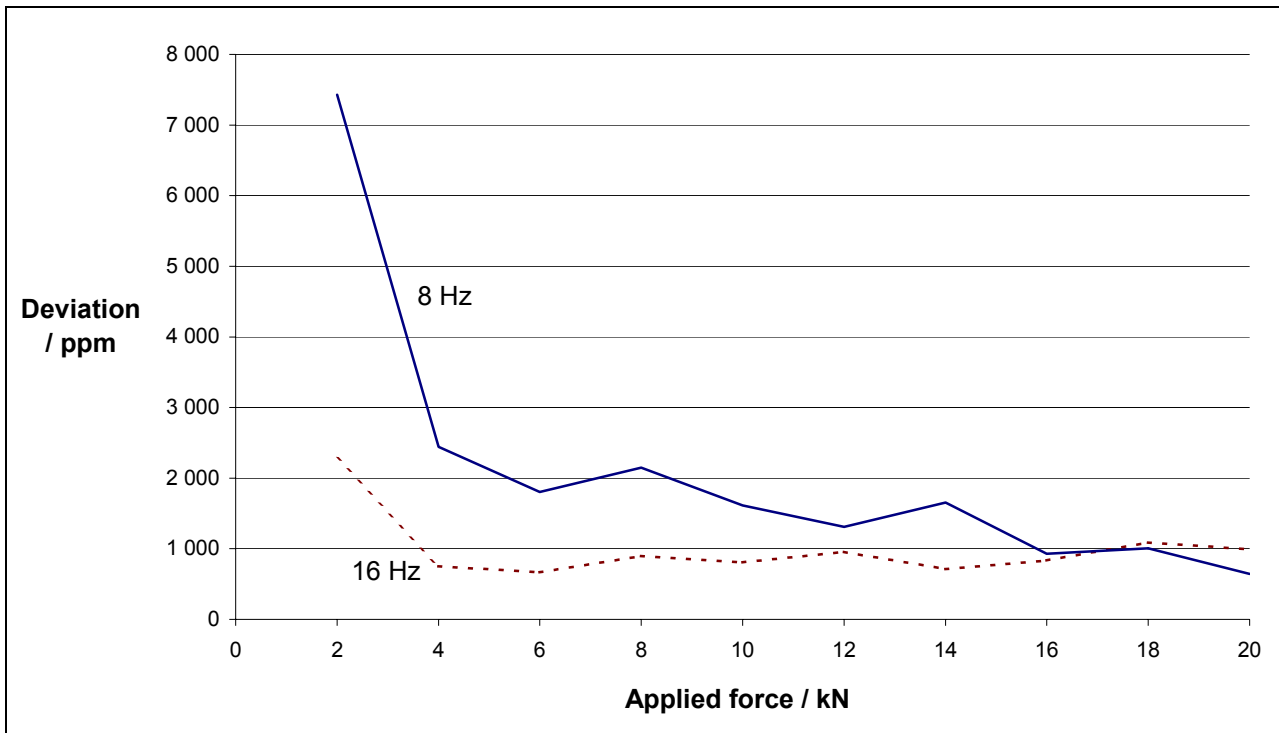


Figure 10 Difference between dynamic and static characterisations at different sample rates

From Figure 10 it is clear that there is a correlation between sample rate and the deviation from the deadweight readings. Another trend which is repeated in Figure 11 and Figure 12 is the way deviation decreases with increasing load. In attempting to understand the effects of sample rate on the deviation, the process needs to be considered. In combining the time axes for the two load devices the last data points for which the full load was still applied were taken and the corresponding times were matched accordingly. However there is an associated uncertainty regarding the exact time at which unload began, that is equal to the time difference between two successive data points.

The difference between these errors for the two load devices will cause a time lag between the two curves. This is illustrated in Table 9.

	Sample rate / Hz	Maximum Lag / s
Mimicking device	16.63	0.060
Load device	20.54	0.049

Table 9 Sample rates from Table 6 and the associated lag

This corresponds to an uncertainty in the force reading given by the equation

$$\Delta F = \text{Ramp rate} \times \Delta T \quad \text{Equation 2}$$

This can be simplified to

$$\Delta F = \frac{\text{Ramp Rate}}{\text{Sample Rate}} \quad \text{Equation 3}$$

For the sample rates in Table 9 and a ramp rate of 100 N/s the maximum uncertainty in the force would be 6 N. This uncertainty is proportionally more significant over the lower applied forces, which is consistent with the profiles seen in Figure 11, Figure 12, and Figure 13.

Table 10 shows the difference in deflections between the static characterisation as given in Table 4 and the dynamic characterisation given in Table 5.

Ramp Rate		100 N/s	200 N/s	1 kN/s
Loading Device kN		Mimicking Device mV/V		
2		0.000 18	0.000 57	0.002 30
4		0.000 12	0.001 09	0.002 57
6		0.000 16	0.000 93	0.001 99
8		0.000 29	0.000 85	0.002 77
10		0.000 32	0.000 75	0.002 40
12		0.000 46	0.000 80	0.002 82
14		0.000 40	0.001 17	0.003 28
16		0.000 53	0.001 43	0.002 31
18		0.000 78	0.001 02	0.002 41
20		0.000 79	0.000 99	0.001 36
Sample rate / Hz	Mimicking device	16.63	16.22	16.16
	Loading device	20.54	20.48	20.51

Table 10 Difference in deflections between dynamic and static characterisations at different ramp rates

As before the differences were plotted in terms of ppm deviation from the static characterisation values in Table 4. This is shown in Figure 11.

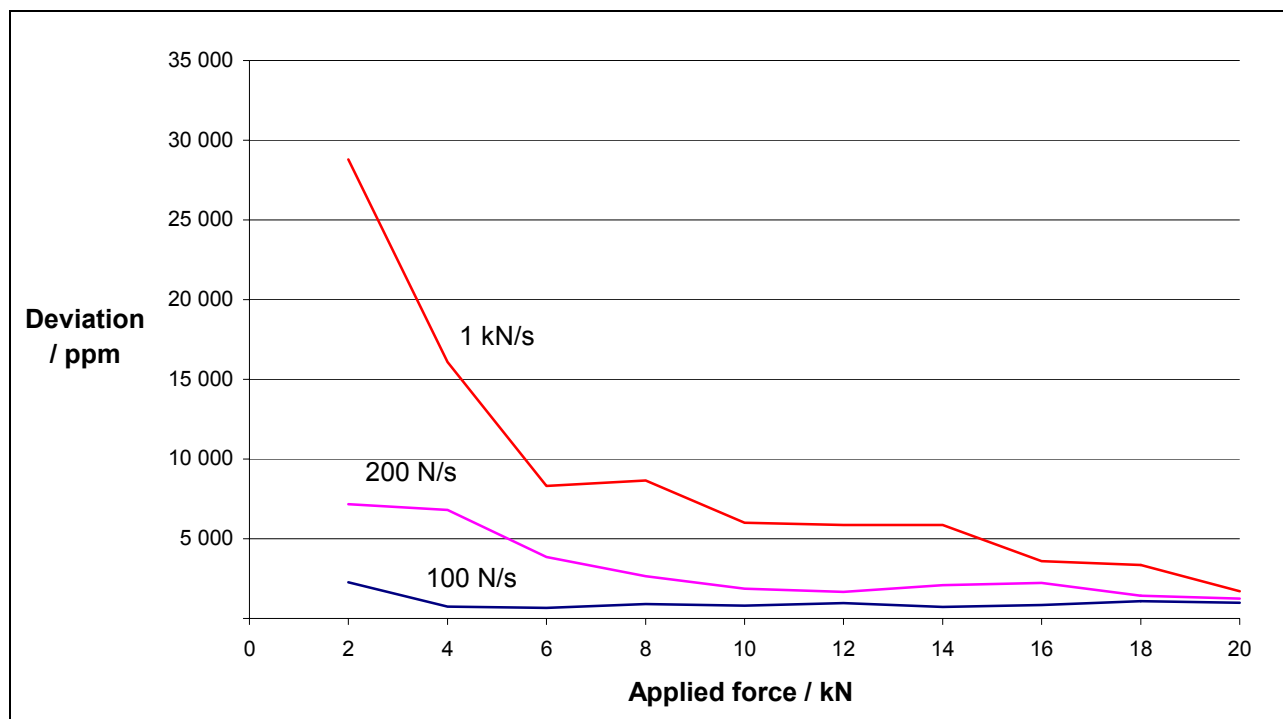


Figure 11 Difference between dynamic and static characterisations at different ramp rates

The effects of ramp rate on deviation from the static calibration can be seen in Figure 11. The graph is consistent with Equation 3. The influence of creep will differ with ramp rate although this is difficult to estimate due to other influences.

The repeatability for the three series in Table 7 is shown in Figure 12. The measure of repeatability is given by the spread in ppm.

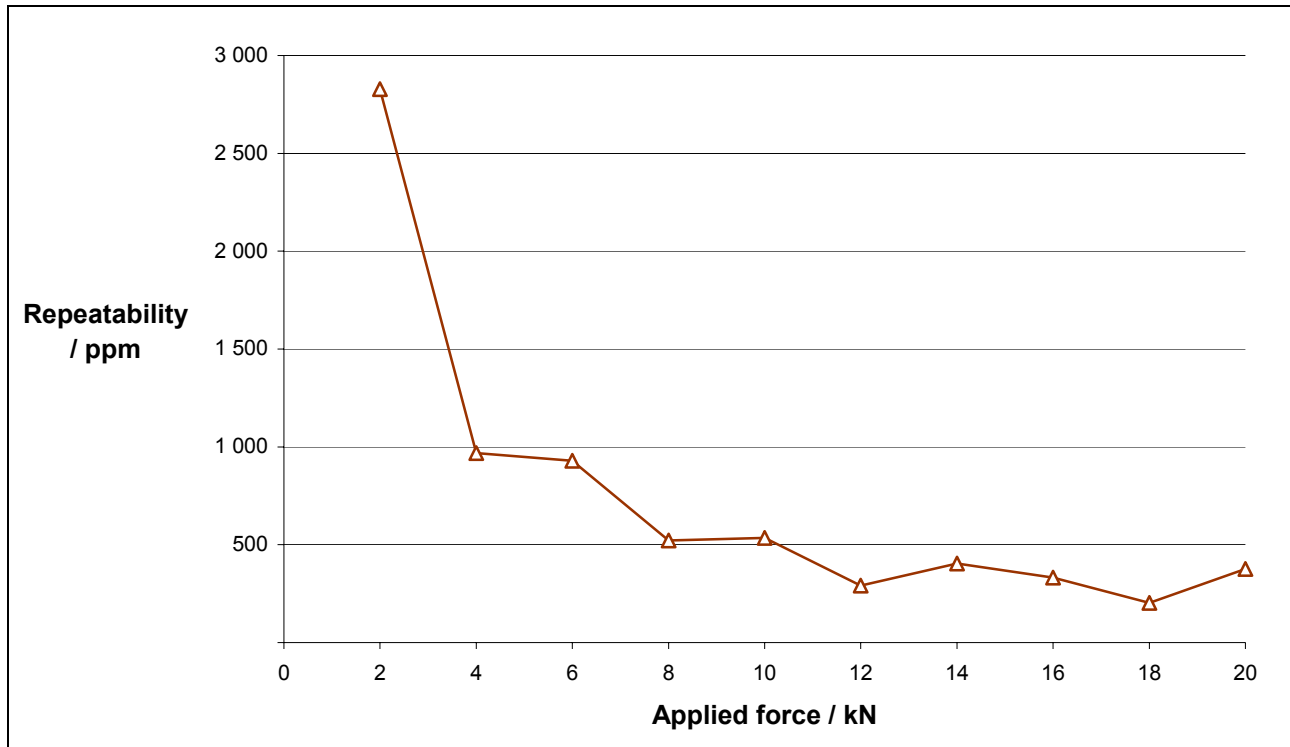


Figure 12 Repeatability of the data series in Table 7

The dynamic process shows repeatability to within 500 ppm for an applied force in excess of 10 kN. In evaluating the repeatability, the effects due to creep can be ignored. The results from the static calibration show that creep is a well-defined process and it can be assumed that its effects will be constant across repeated runs such that its variances can be considered negligible.

The results and uncertainties compare favourably with relative errors of force proving instruments quoted in the BS EN ISO 376:2002 standard. For the series in Figure 12 the results are within Class 0,5 specification between 8 kN and 20 kN and within Class 1 specification between 4 kN and 8 kN. While the protocol does not follow a complete calibration method, it does provide an indication of the potential of the dynamic characterisation process.

It is apparent that the deviation from the static characterisation (Figure 10) is two to four times greater than the deviation from the repeatability (Figure 12). One reason for this could be the effects of creep. The static calibration readings were taken 60 s after the application of the load according to best practice. Figure 3, Figure 4, and Figure 5 show the creep pattern for both load devices over this time period. As during the dynamic characterisation readings were taken instantaneously, the contribution of creep should be significantly reduced. The magnitude of the creep response is approximately 375 ppm for the mimicking device and 140 ppm for the loading device. As the creep response for the mimicking device is positive while for the loading device it is negative the overall effect for the two load cells in series will be additive. This gives a potential uncertainty of over 500 ppm for the dynamic calibration when comparing those values to those taken during the static calibration. Another indication of the influence of creep is that for every dynamic characterisation the reading is less than the corresponding reading for the static calibration (i.e. the mimicking

device lags the loading device). The uncertainty associated with the synchronisation of the two curves is random and in the case when the sampling rates for the two load devices are similar, the direction of the lag should be random. The fact that this is not reflected in the results indicates the presence of a systematic uncertainty, which contributes to the overall uncertainty. The maximum uncertainty due to the effect of synchronisation can be calculated from Equation 3. This is plotted alongside the repeatability in Figure 13. The two curves give very good agreement, and suggest that the synchronisation effect is the significant contribution to the error in the relative repeatability of the process.

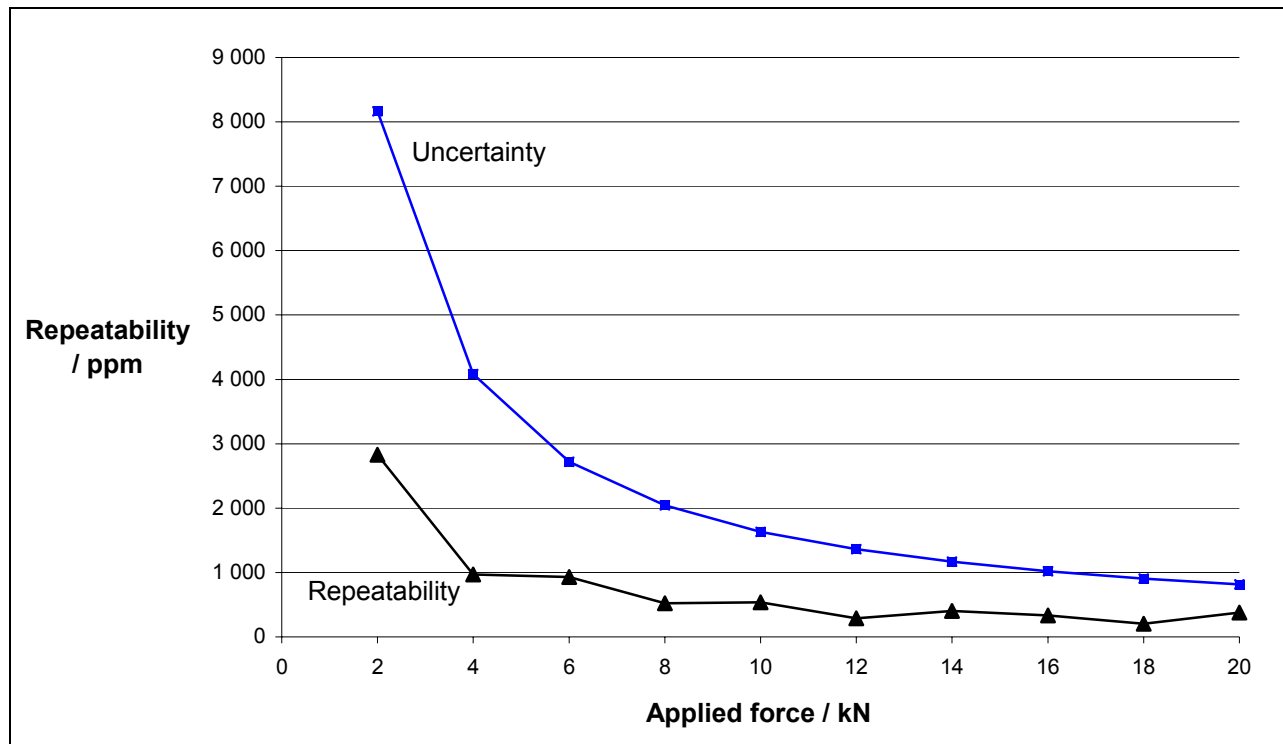


Figure 13 Estimated uncertainty due to synchronisation plotted with the repeatability

Figure 14 shows the estimated uncertainty due to synchronisation and creep for the sampling rate used in Table 7. Note that while the calculated synchronisation uncertainties in Figure 13 and Figure 14 are based on the same sample rates, a difference arises because in Figure 13 the estimate is based on the maximum difference between two runs, while in Figure 14 the estimate is based on a single run. These curves are consistent with the shape and magnitude from the experimental data in Figure 11, Figure 12, and Figure 13.

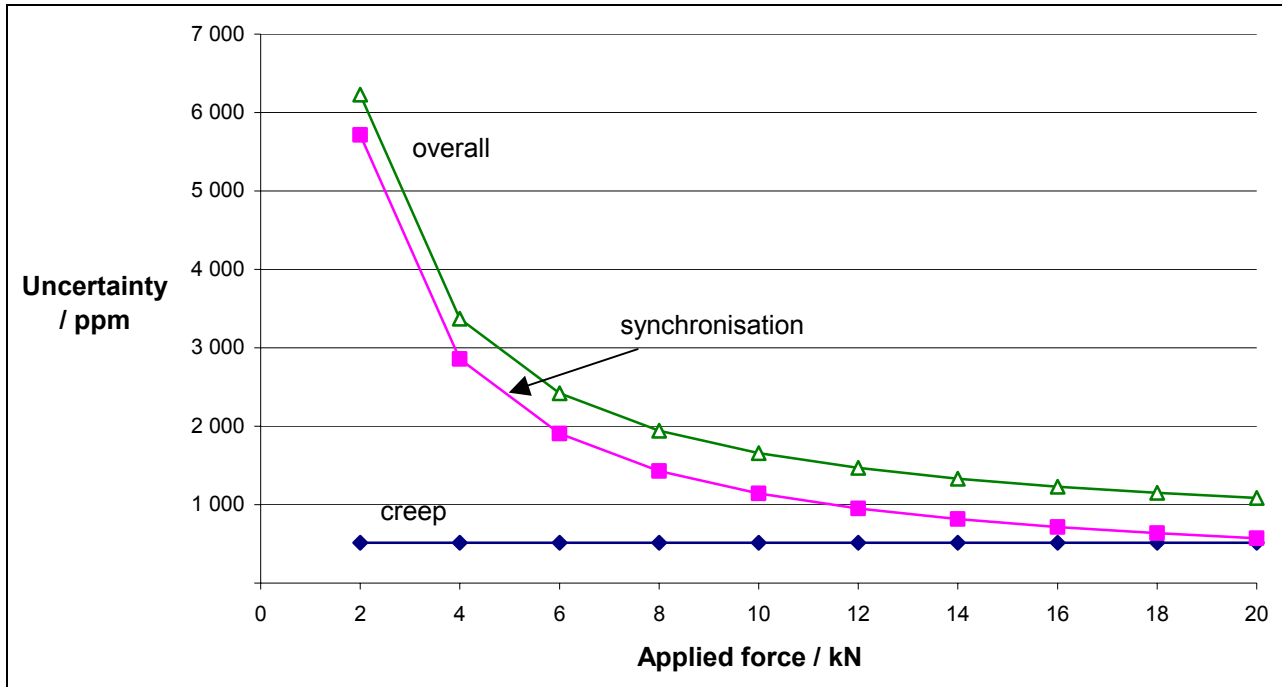


Figure 14 Estimation of uncertainty due to synchronisation, creep, and the combined effect

Both creep and synchronisation have been identified as major contributors to the overall uncertainty of the dynamic calibration process. The size and randomness of the uncertainty due to synchronisation has provided a barrier to possible identification of further uncertainty contributions.

Another source of uncertainty is the difference between the applied force in the dynamic characterisation as given by the loading device and the applied force from the static characterisation defined by the 20 kN deadweight machine. With the experimental method followed it was not possible to quantify this uncertainty.

The work done allows the parameters to be set for a future dynamic calibration. For a target uncertainty budget the necessary sampling rate could be estimated. The limitations of sampling rate dictated that most of the experimental work was at a ramp rate of 100 N/s. At this ramp rate, a dynamic calibration consisting of three runs and a preload could be completed in twenty minutes, compared to several hours for the equivalent static calibration. From a process point of view, there is little to be gained from going much above a 500 N/s ramp rate, which would give a process time of under one minute for a single run.

One way of minimising the error due to synchronisation would be to introduce more load off points into the process. After the main part of the calibration, a series of five forces could be applied and then removed after a short hold. This would provide a set of load off points. The difference between the average of the two sets could be taken as the offset to match the two profiles.

5. Conclusions

The dynamic characterisation process has produced repeatability results within the BS EN ISO 376:2002 Standard Class 0,5 specification in the range 12 kN - 20 kN. This range can be extended if a higher sampling rate were to be used. At a ramping rate of 100 N/s, a dynamic calibration process, comprising of preload and three measurement series, could be completed in twenty minutes, in contrast to several hours for the equivalent static process.

Results for the dynamic characterisation were compared to those from the static deadweight calibration. At the maximum sampling rate of 16 Hz and a ramp rate of 100 N/s the deviation was around 1 000 ppm for the range 4 kN – 20 kN.

Two major sources of uncertainty, creep and synchronisation were identified. These were quantified, from experimental data in the case of creep and by a model in the case of synchronisation. Both gave good agreement with the data from the dynamic characterisation.

The sampling rate was shown to be a limiting factor on the overall uncertainty. However, the model developed can be used to estimate the parameters required (sampling rate, ramp rate) in order to achieve a particular level of uncertainty. In addition, a process was suggested to reduce the uncertainty contribution due to synchronisation for a given sampling rate.

An increase in the sampling rate would also allow further contributions to uncertainty to be identified and a better understanding of the process to be gained.

The report concludes that a dynamic calibration procedure could be developed of sufficient accuracy to calibrate load cells to the BS EN ISO 376:2002 Standard.

6. References

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Acknowledgement

The work described in this report was funded by the Department of Trade and Industry, under the National Measurement System's Mass Programme 1999-2002.