Lateral blade movement in clamps

Experiment

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1. Background:

During alignment procedures on the quad, it was found that pitching the top and UI masses caused permanent pitch changes at the test mass. It was felt that this may be related to permanent lateral displacement of the blades tips.

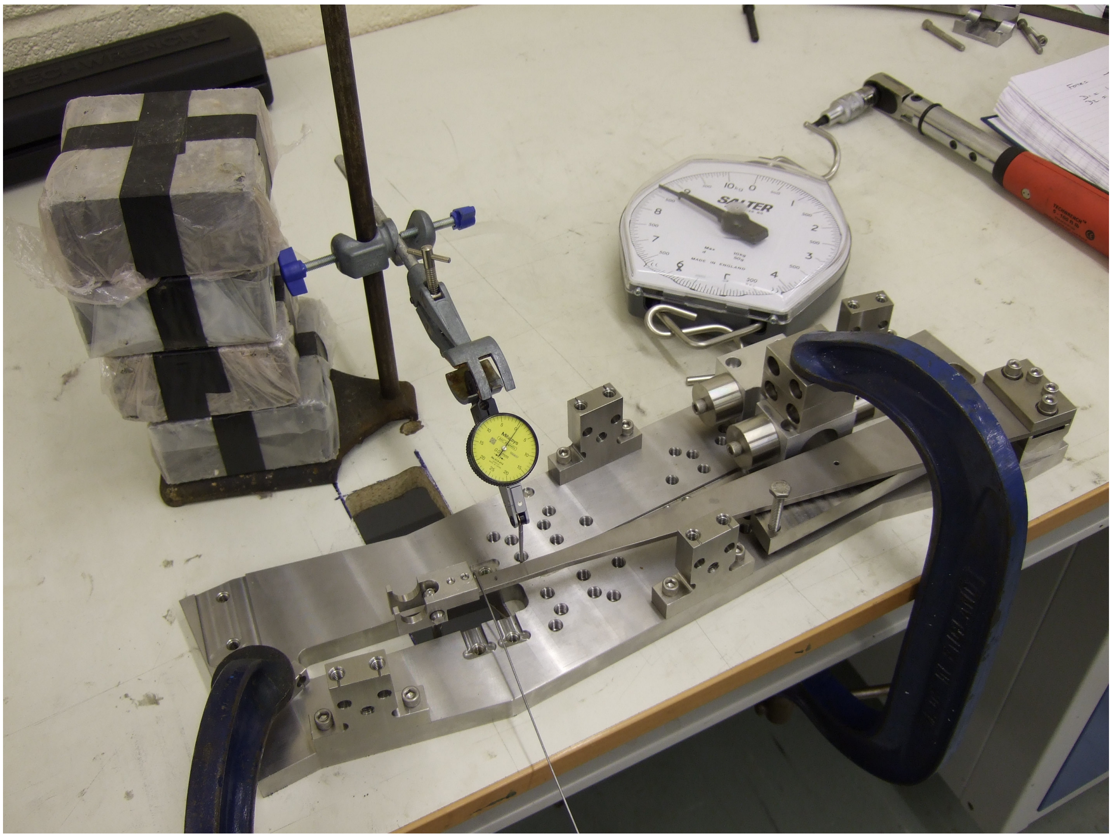
2. Objective:

The objective of this experiment is to determine the effect that the clamp bolt torques and lateral forces at the tips have on the blade lateral displacement. It has been queried whether blade clamp shaping (crowning) due to filing could reduce the blade clamping efficiency, and this also will be investigated. There is also a more recent clamp design for these clamps, with four bolts instead of two, so the effect of this on the lateral movement of the blade will also be investigated.

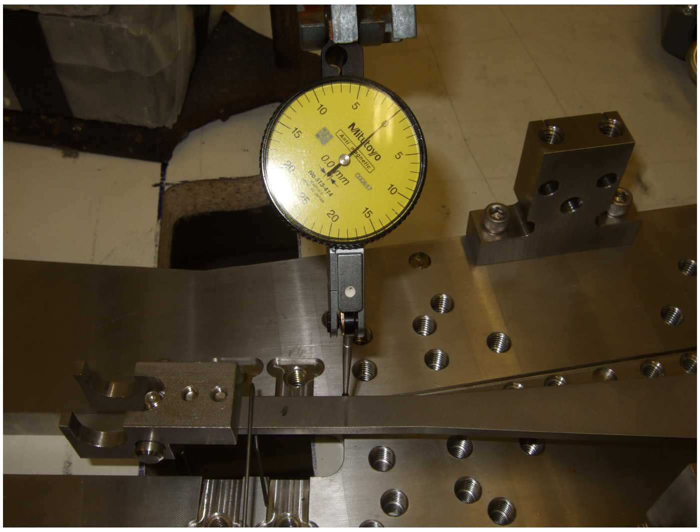
3. Setup

A UI mass was extracted from the RAL Quad noise prototype, and its top plate and one blade removed. It was bolted down flat on a bench, and a weight hung to pull the blade flat. A dial test indicator (DTI) was placed against the side of the blade, and a spring balance was attached to the tip of the blade so allow controlled lateral forces to be applied. In the figure below, the DTI is fixed to a lab stand on the adjacent table. In later tests (4 bolts onwards), the DTI was fixed to steel blocks screwed directly to the baseplate of the mass.

The setup is shown below:



4. Procedure



A pre defined lateral force of 1kg was exerted laterally on the blade, and the DTI reading recorded. The blade was then allowed to spring back, and the permanent deflection recorded. This was repeated in 1kg increments up to 10kg. The tightening torque on the clamp bolts was changed and the experiment repeated at the now torque. This was done first for blade clamps with two bolts, then later for clamps with four bolts. The results have been recorded and graphed to examine the effect of bolt torques and blade clamp geometry. In some tests, a piece of shim material was introduced into the clamp to simulate the effect of imperfect filing of the clamp. In later tests, the clamp was filed to reproduce as far as possible the situation at LASTI (where all the clamps have been filed). In other tests, cleaning with and without air baking was done.

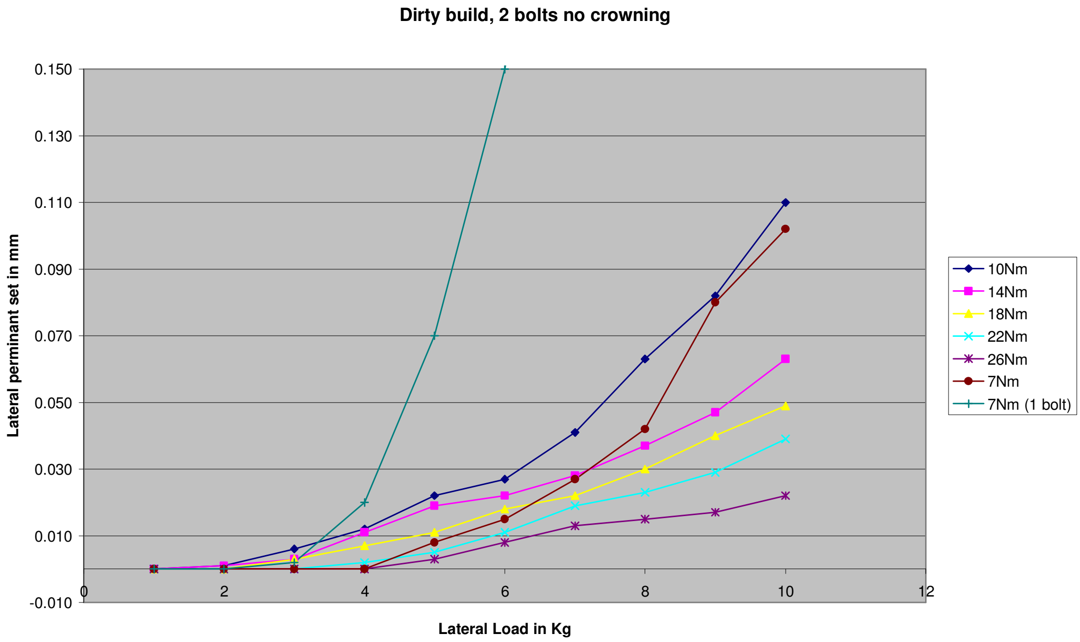
When tightening the bolts, the "inner" bolts – those which clamp the blade only – were given the full range of tightening torques. We used high strength steel bolts. The "outer" bolts – those which clamp the blade and also hold the blade clamp down to the baseplate – could only be tightened to about 23 N.m because they were stainless steel.

The DTI had intervals of 10micron; these were interpolated by eye in the results below, but the 1 micron digit should be treated with extreme caution.

In the real suspension, for a tilt of 150mRad at the UIM, the lateral force will be about 0.15*40 or ~5kg. The reported deflection at LASTI, which we were looking to reproduce, was ~100 microns.

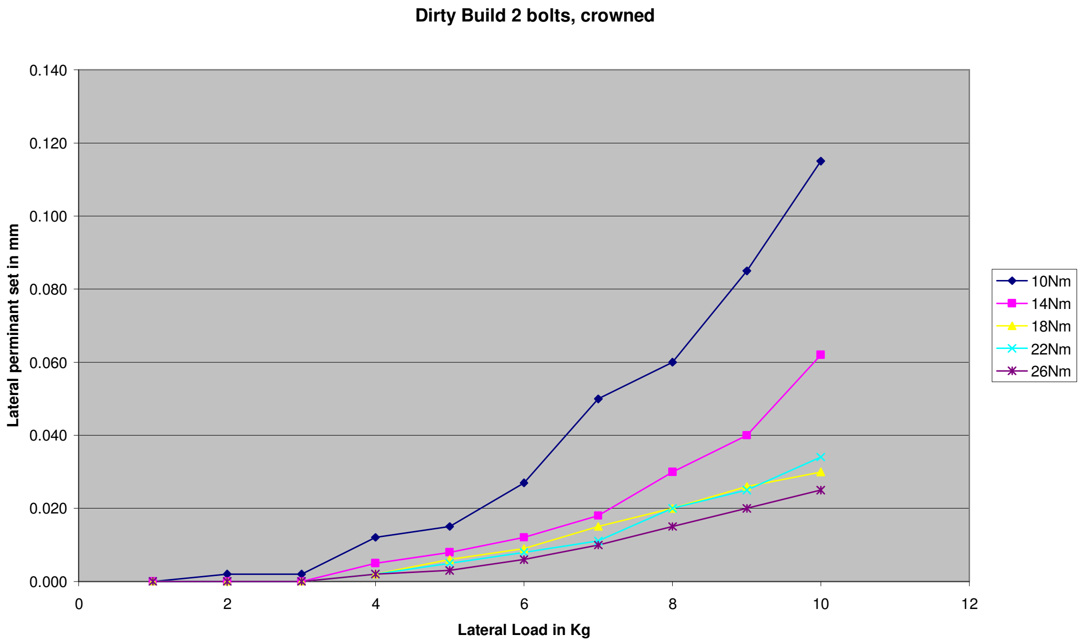
5. Results:

5.1 2 bolts, no shim , dirty



The residual deflection with a 5kg lateral force, for a 22Nm tightening torque, is less than 10 microns. However, by tightening only one bolt to 7Nm (the other bolt was left loose) we were able to reproduce the ~100 micron deflection seen at LASTI.

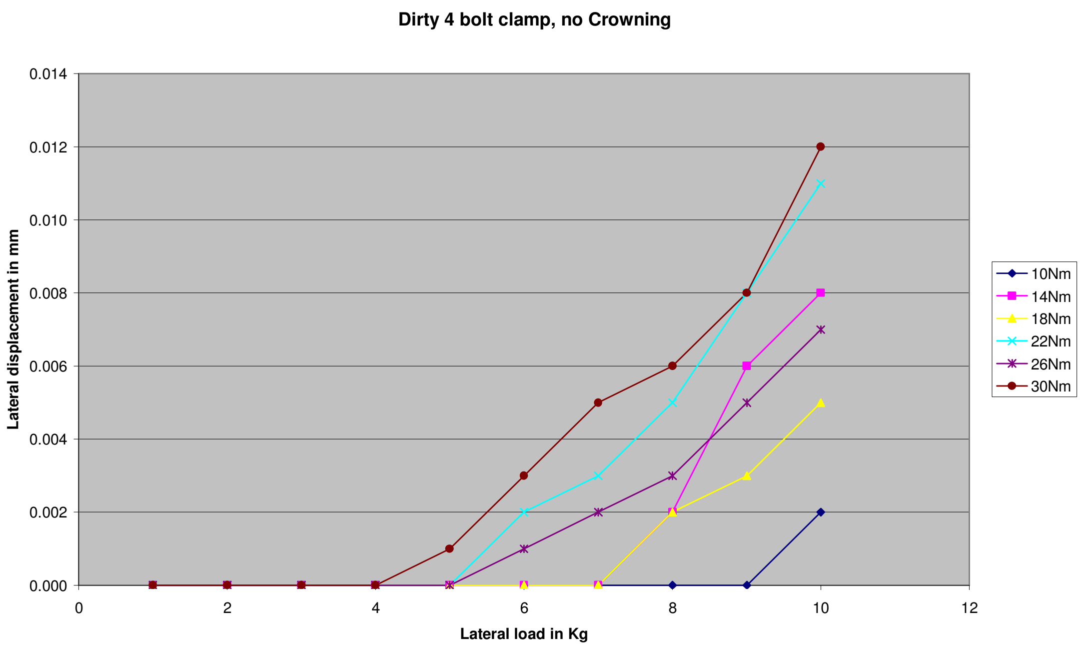
5.2 2 bolts, with shim , dirty



The shim, put there to simulate the effect of the crowning that might be associated with filing, has had little effect.

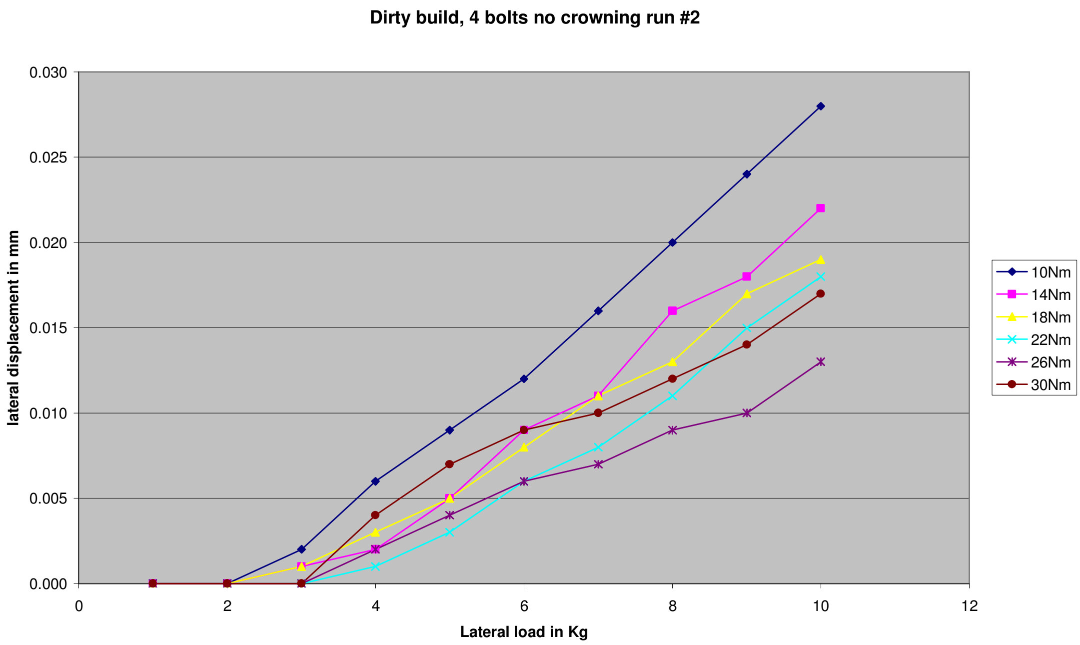
5.3 4 bolts, no shim , dirty

5.3.1 First run



Note that in these results the higher bolt torques seem to give larger, rather than smaller, displacements. It is not clear why this is.

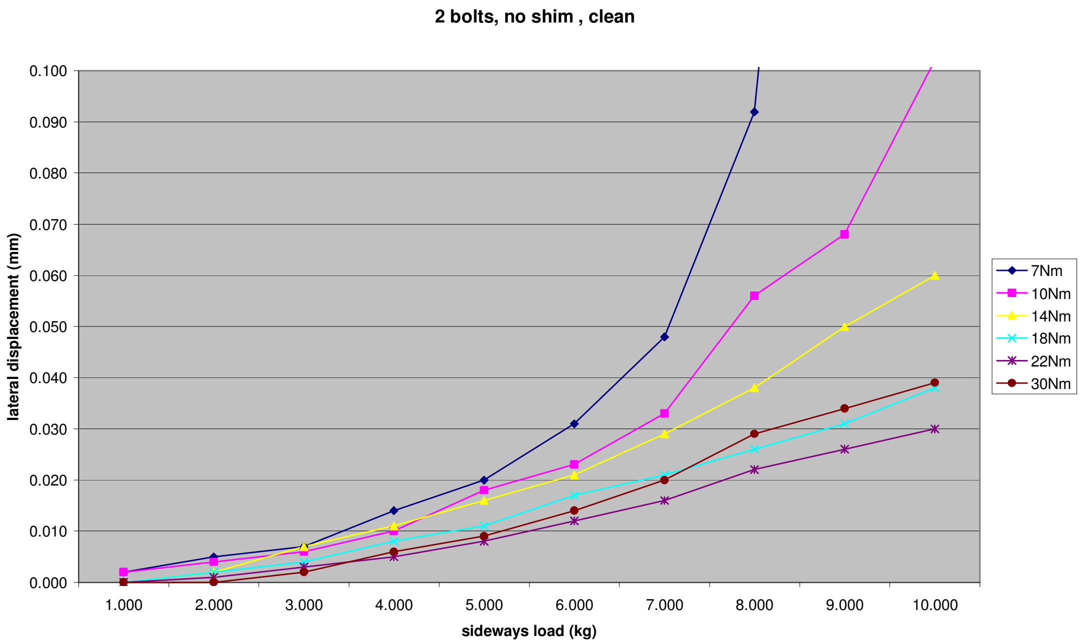
5.3.2 Second run



In this run, XXXXXXXXXXXXXXX was done. This has had two effect s- one is that the large bolt torques now give smaller deflections (as expected). The second is that the curves of the graph tend to be bilinear with a portion at zero deflection and then a ~straight line. The additional bolts have significantly reduced the deflections.

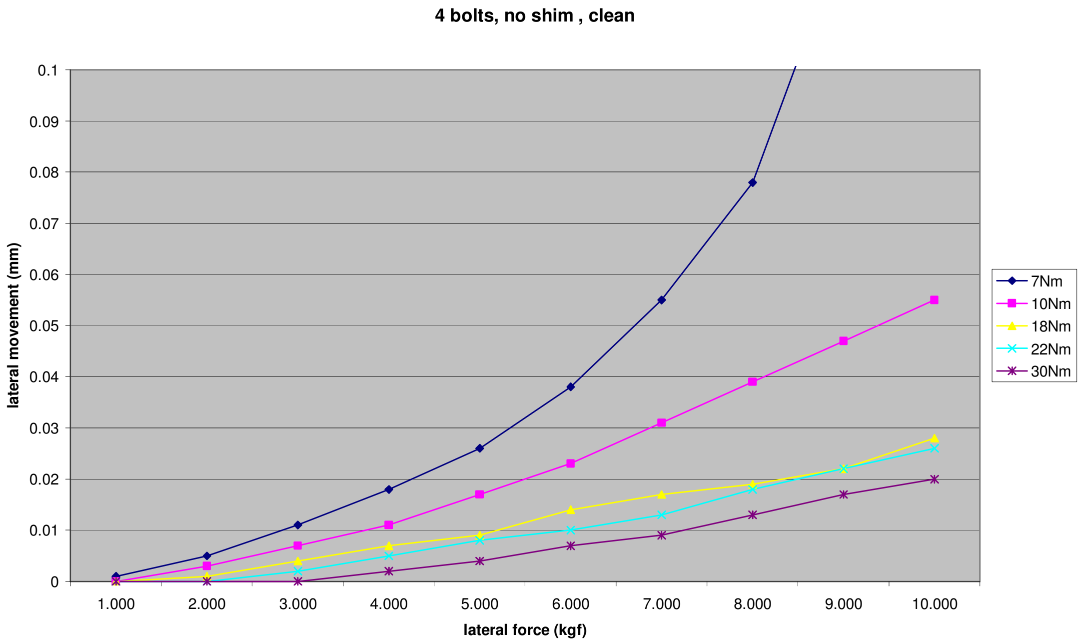
5.4 2 bolts, no shim, cleaned

For this test, the upper and lower clamp jaws, the blade, and the bolts were cleaned by immersing in alcohol in an ultrasound bath twice. The tapped holes in the baseplate were cleaned with alcohol and a cotton bud until the bud came away visually clean.



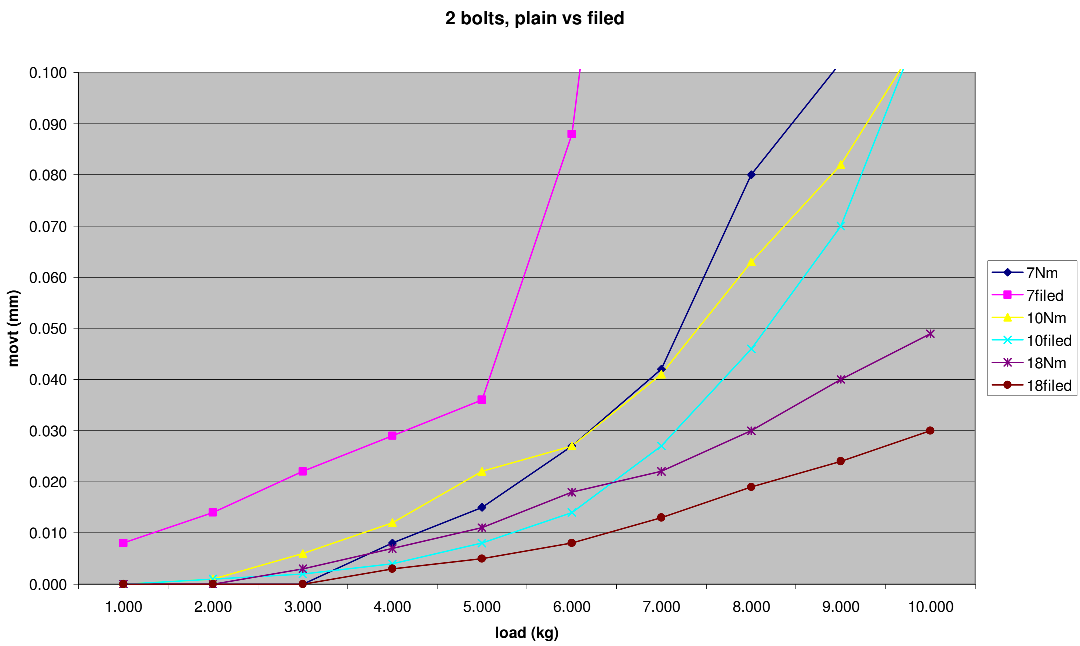
There is no dramatic effect from the cleaning.

5.5 4 bolts, no shim , cleaned



This time the additional bolts don't seem to have made so much difference.

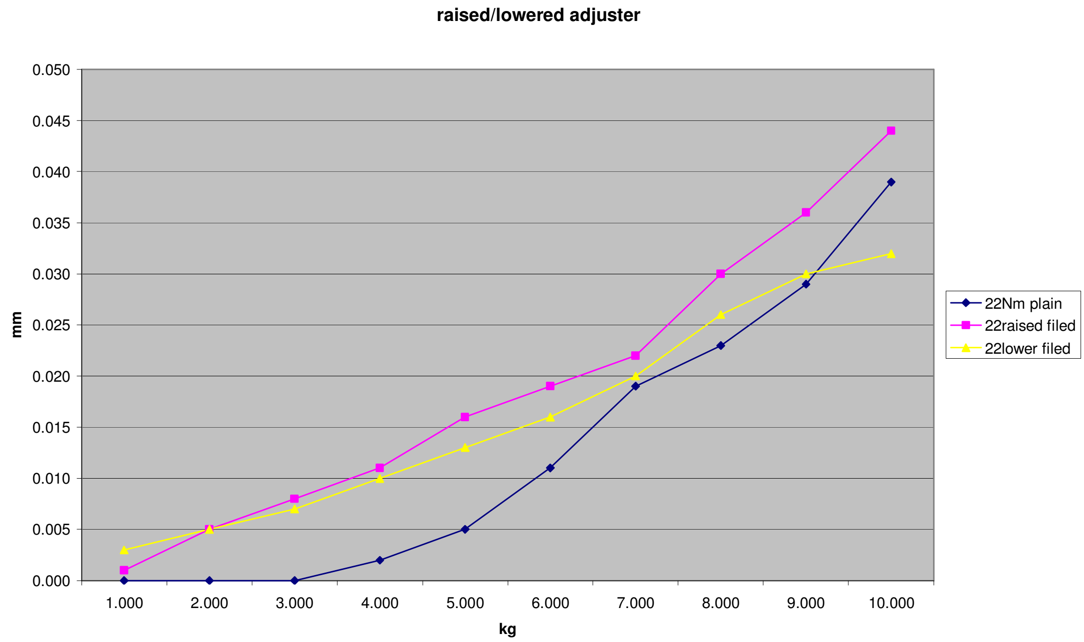
5.6 2 bolts, filed clamp



And there is no obvious effect from a genuinely filed clamp. The filing was done in such a way as to emulate the worst reasonable outcome of filing – the end of the clamp was made non-flat and non-level.
However, we did manage to give a 100micron tip movement with 5kg lateral load by reducing the tightening torque to 7Nm and tightening only one of the two clamp bolts.

5.7 2 bolts, raise/lower blade rotator

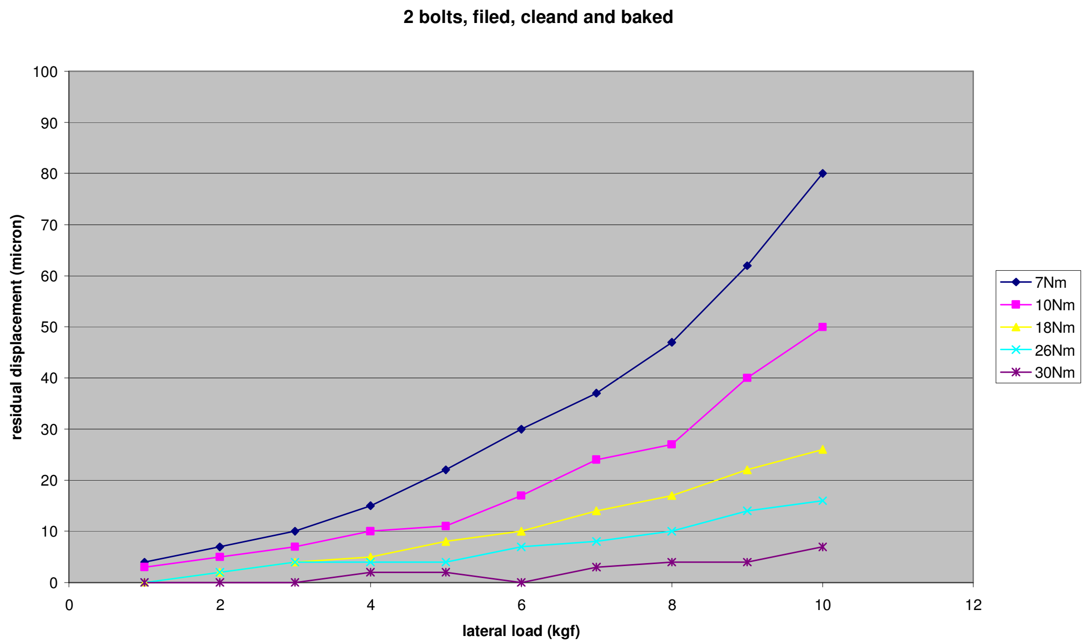
For this test, the blade rotator was raised or lowered after the bolts had been done up.



No dramatic effect.

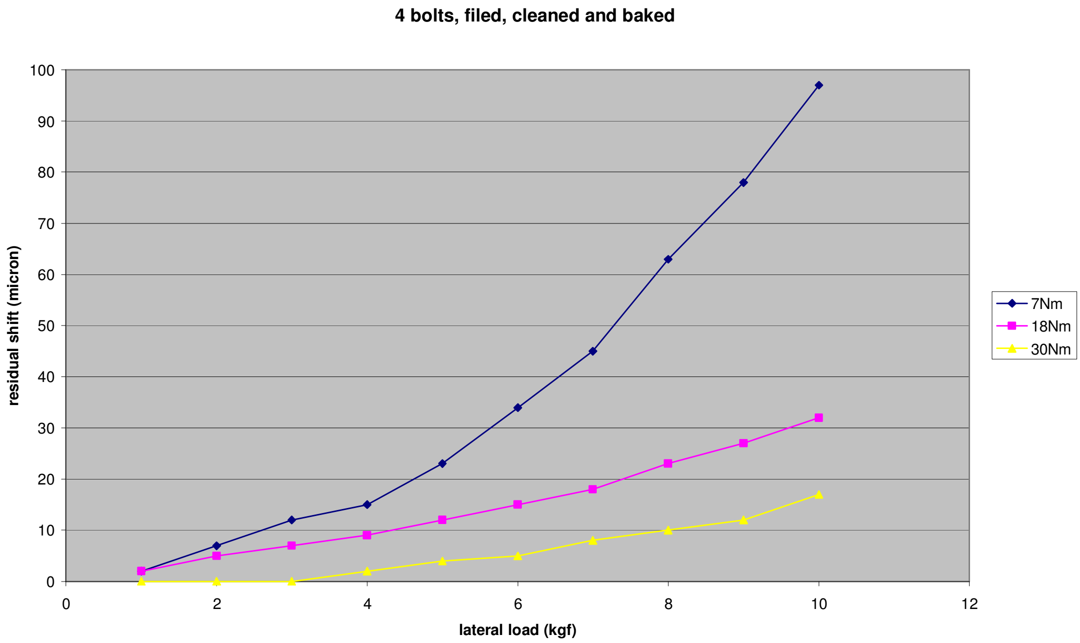
5.8 2 bolts, filed, cleaned and baked

For this test, all of the parts were cleaned as described above and then all the parts except the baseplate were wrapped in aluminium foil and baked in an oven at 120C for 24 hours.



No dramatic effect.

5.9 4 bolts, filed, cleaned and baked

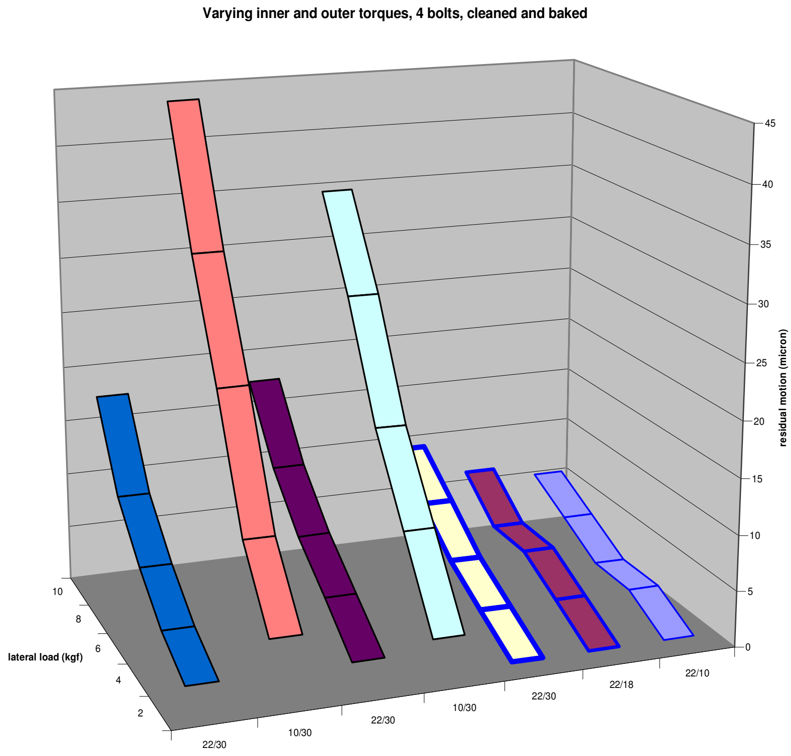


This confirms the previous clean result, that the extra bolts don't make much difference.

5.10 Variation of inner vs outer bolts

For this series of tests, the torques on the bolts were carried as follows. Define the inner bolts as the four bolts that clamp only the blade. Define the outer bolts as the two bolts that clamp the blade and hold the blade clamp down on the baseplate.

Outer torque, N.m	22	22	22	10	22	10	22
Inner torque N.m	10	18	30	30	30	30	30
Lateral load, kgf	Recorded displacement, microns						
2	0	0	0	3	2	5	2
4	2	2	2	10	5	11	4
6	2	4	4	17	8	22	7
8	4	4	7	27	12	32	11
10	6	7	10	35	18	44	18



This result suggests that the torque on the outer bolts is at least as important as the torque on the inner ones.

6. Conclusions

The main conclusions are:

1. We have not been able to reproduce the large (~100 micron) tip deflections seen at LASTI, except when we used larger lateral loads than they did and when we used very low tightening torques (7Nm for 5kgf lateral, 10Nm for 10kgf lateral). When we used a torque of ~22NM, as they have, the residual displacement for a 5kgf lateral load is of order 10 microns.
2. Cleaning, or cleaning and baking, does not seem to have much effect on the results.
3. Adding the extra two bolts had a significant effect in the dirty case but not in the clean cases. (However, there were dome questions over the dirty results).
4. The torques on the outer bolts is as important as the torque on the inner bolts.