DRAGON Q1, Q2 Alignment
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The vertical positions of DRAGON quadrupoles Q1 and Q2 were adjusted on November 27 and 28, 2007. This report presents the evidence that their heights were wrong, the methods used to monitor quad positions and the results of the adjustment. Those taking part in the exercise were C. Ruiz, P. Machule, C. Vockenhuber, U. Hager and the author. Valuable technical advice was given by B. Gasbarri and M. Jansz.

1 Evidence for misalignment

1.1 Beam steering

Standard DRAGON tuning procedure is based on the condition that the centroid of a beam at the Charge Slit focus should not move when the quads Q1 and Q2 are turned off, defining a "magnetic axis" for the Q1/Q2 doublet. A longtime feature has been that when a beam was tuned to put it on this axis, it would be 3 mm high with respect to the nominal centre at the Charge slits (YSLITC). This points to a problem with the vertical position of one or both of Q1 and Q2.

1.2 Magnet survey

In May 2007 Michael Jansz, as part of his summer student project, used the TRIUMF Alignment Group's Leica 5005 TOTAL survey station to find the relative positions of the DRAGON separator magnets. (See his report "TOTAL Station Surveying" of June 19, 2007.) There was some evidence from theodolite measurements that the floor under the front end of DRAGON has shifted since it was installed. There were no previous measurements by TOTAL against which to check, but comparison of the current height of Q1 relative to Q6 and of Q2 relative to Q3/Q4/Q5/Q7 could be made. The survey found that Q1 was higher than Q6 by 1.5 mm and Q2 was higher than Q7 by 1.7 mm. (Caveat: the survey fixtures on quads were attached to corners of the return yokes, not necessarily the identical distance from magnetic centres for different magnets of the same nominal size.)

1.3 Vibrating wire data

Stronger evidence was provided by Michael Jansz' second project, which was to locate the magnetic centres of the separator quads using a vibrating wire technique (his report of August 24, 2007). A theodolite was used to relate the nominal beam height to the position of the wire. The dominant systematic uncertainty in magnetic position of Q1 and Q2 was the estimated 0.5 mm possible error in relating wire position to the reference mark, a scribed line on a steel pillar on the south wall of the ISAC-1 experimental hall. Excluding this source of error (which would be common to Q1 and Q2), the other sources of error were estimated to be 0.2 mm. The technique gave also an estimate of mis-orientation of the quads ("pitch" and "yaw"). The positions and angles of Q1 and Q2 relative to the nominal ion-optical axis are given in Table 1.

1.4 Improper mounting of Q1/Q2

While preparing for the adjustment procedure, it was noted that Q1 was not sitting properly on its alignment fixtures. Each quad sits on a baseplate which carries screws for adjustment of horizontal position and orientation (yaw). The baseplate, in turn,

Table 1: Quad positions measured by the vibrating wire method. Positive x is to the left looking downstream; positive y is up; positive pitch is clockwise looking in the direction of decreasing x; positive yaw is clockwise looking in the direction of decreasing y.

	Q1	Q2
x (mm)	1.52	0.15
y (mm)	2.05	1.23
Pitch (mrad)	4.42	-0.21
Yaw (mrad)	4.71	3.85

is supported from a sub-frame by three fixtures (flat, groove and cone mating points) which allow adjustment of height, pitch and roll of each quad. Finally, the subframe is bolted down to a main support frame. It was found that (a) some of the bolts between sub-frame and frame were loose, (b) there was an air gap of approximately 1 mm visible at the "groove" fixture of Q1, (c) there were no tie-down bolts between the baseplates and sub-frame and (d) a retro-fitted support for gate valve IV11 bolted to Q1 could have been exerting a torque on it and, to a lesser extent, to Q2.

2 Adjustment procedure

2.1 Three measurements of quad height

The first method was using the TOTAL survey instrument to monitor quad positions with respect to a reference point (the 'b' position of dipole MD2) and direction (putting the 'b' point of MD1 on axis). The standard Alignment Group's procedure was followed: take a repeat measurement at survey point and repeat the first point to verify that the instrument had not been bumped. The Axyz software was used to transform the raw range/dip/azimuth into the MD2-MD1-based system. These were further transformed by a spreadsheet calculation to give "personalized" coordinates for each magnet (x, y, z, pitch, roll, yaw). Reproducibility appeared to be ≈0.2 mm rms for x or z and slightly better for y. (The TOTAL station knows which way is up and measures angles much better than it measures ranges.)

The second method applied to Q1 only: dial gauges were mounted with magnetic clamps so as to measure the gap between sub-frame and baseplate at positions close to each of the three vertical adjustment screws. These gauges indicated changes from the initial gaps to better than ± 0.1 mm.

The third measurement involved alpha particles emitted from a Gd source mounted at the centre of the gas target cell and detected in a double-sided Si strip detector (DSSSD) installed downstream of the Charge slits. Vertical position centroids could be measured to a small fraction of the 3 mm pitch of the strips. The vertical profile at the location of YSLITC was measured by a vertical scan of YSLITC position for a small Width setting (typically 2 or 3 mm).

2.2 Adjustment sequence

1. tighten bolts between frame and sub-frame, install and tighten tie-down bolts between baseplates and sub-frame, bolts loosened on bars between Q1 and Q2
2. Q1 lowered by 1/2 turn on each of the (14 threads-per-inch) adjustment screws (25.4*0.5/14 = 0.91 mm)
3. Q2 lowered by 1/2 turn on each of its adjustment screws
4. Q1 raised by 1/4 turn on each of its adjustment screws

3 Results

3.1 TOTAL data

The processed coordinates of interest are presented in Table 2. To assess height changes, we consider the average of points ‘a’ and ‘b’ only, because they are insensitive “roll” of the quads.

Table 2: Y coordinates of quad survey points, deduced pitch/yaw and a-b hole separation as measured by the TOTAL station. Points a and b are on top of the quad yoke, point c at beam-height “outside” corner of the yoke. Positions are in mm, pitch and yaw in mrad.

	May’07	Initial Nov’07	After Q1 lowered	After Q2 lowered	After Q1 raised
Q1a	314.88	314.97	313.98		314.72
Q1b	315.25	315.28	314.21		314.89
Q1c	59.65	59.80	59.19		59.80
Q1 yaw	-0.8	0.3	1.7		0.4
Q1 pitch	3.6	3.0	2.2		1.7
Q1 ab sep	101.60	101.80	101.84		101.64
Q2a	406.39	406.38	406.45	405.59	
Q2b	406.45	406.43	406.70	405.79	
Q2c	59.83	59.86	59.89	59.19	
Q2 yaw	-1.5	-1.7	-1.5	-1.6	
Q2 pitch	0.3	0.2	1.0	0.8	
Q2 ab sep	241.25	241.23	241.30	241.17	

The horizontal separation of points ‘a’ and ‘b’ is expected to be 101.6 mm (4”) on Q1 and 241.3 mm (9.5”) for Q2. Within 0.2 mm, this is what was observed. In the vertical it appears that the heights of Q1 and Q2, relative to MD2, did not change between May and November. The baseplate tie-down and loosening of the bars between Q1 and Q2 appear not to have changed the height of Q2; for Q1 these operations plus the lowering by 1/2 turn resulted in a 1.0 mm reduction in height.

Lowering Q2 by a nominal 0.91 mm resulted in a reduction in TOTAL's average Y coordinate for 'a' and 'b' of 0.89 mm.

3.2 Dial gauge measurements

Results are given in Table 3. The drop at the SW corner after loosening of the gate valve support and tie-down of the Q1 baseplate (0.89 mm) is consistent with the apparent size of the air-gap that was seen beforehand. Lowering Q1 by 1/2 turn caused the gaps to decrease by 0.97, 0.90 and 1.04 mm for an average of 0.97 mm, to be compared with the expected 0.91 mm for 1/2 turn.

The adjustment upward by 1/4 turn (nominal 0.45 mm) resulted in gaps increasing by 0.43, 0.46 and 0.46 mm for an average of 0.45 mm.

Table 3: Dial gauge readings of gap between Q1 baseplate and subframe, close to the vertical adjustment screws. Point 1 is upstream and below the beam axis; point 2 is downstream and north-east of the beam axis; point 3 is downstream and south-west of beam axis. Readings are in inches.

	Initial Nov'07	After tie-down	After Q1 lowered	After Q1 raised
Point 1	0.000	0.002	-0.036	-0.019
Point 2	0.000	-0.015	-0.050	-0.032
Point 3	0.000	-0.035	-0.076	-0.058

Following the adjustment procedure and when venting had taken place, Q1 again moved: dial gauge readings changed and a gap re-appeared at the south-west support point. Thoughtful examination of the tie-down arrangement led to the conclusion that it was not well-conceived. An alternative arrangement, with pull-down at two transverse points below the centre of the quad, was put in place. After this, the dial gauge at Point 3 read -0.061" and was steady under venting and pumpdown.

3.3 Alpha source

The centroids measured in the Si strip detector downstream of YSLITC are given in Table 4. The net shift in centroid was 3 mm downward, which should correct exactly the previous problem that beam had to be 3 mm high at YSLITC to have Q1/Q2 non-steering.

Table 4: Centroids on a Si strip detector downstream of YSLITC for alpha particles from a Gd source located at the centre of the gas target cell. Q1 strength was reduced 5% from the "standard" tune. Readings are in strips (3 mm pitch). Statistical errors from fits to a Gaussian were typically 0.02 to 0.03 mm.

	Initial Nov'07	After Q1 lowered	After Q2 lowered	After Q1 raised
Centroid	22.8	26.3	25.3	23.9

4 Summary

1. TOTAL survey shows no significant motion of Q1 or Q2 relative to dipoles MD2 and MD1 between May and November 2007.

2. TOTAL survey indicates the adjustments made a net change in height of Q1 by -0.3 mm and of Q2 by -0.7 mm. The apparent rise by 0.7 mm when dial gauges gave 0.45 mm for the final upward adjustment of Q1 may be an indication of a problem with the last data set; if so, a better estimate of net Q1 movement would be 0.25 mm greater, i.e. -0.55 mm. The Q1 pitch angle was reduced by 1 mrad.

3. Dial gauges indicated Q1 height change of -0.9 mm. They were insensitive to possible motion of the subframe relative to the main frame.

4. The vibrating wire measurements called for downward movement of Q1 to be 0.82 mm greater than the correction at Q2. Whichever is chosen for the Q1 shift (-0.9, -0.55 or -0.3 mm), the measured Q1 shift is less than called for by the vibrating wire work.

5. The alpha data indicate the Q1/Q2 adjustment should eliminate the "3-mm" problem at YSLITC.