Transverse Forces in the CBETA v6/v6.5 Magnets

Stephen Brooks 2017-Jun-16 CBETA machine note #17

1. Introduction

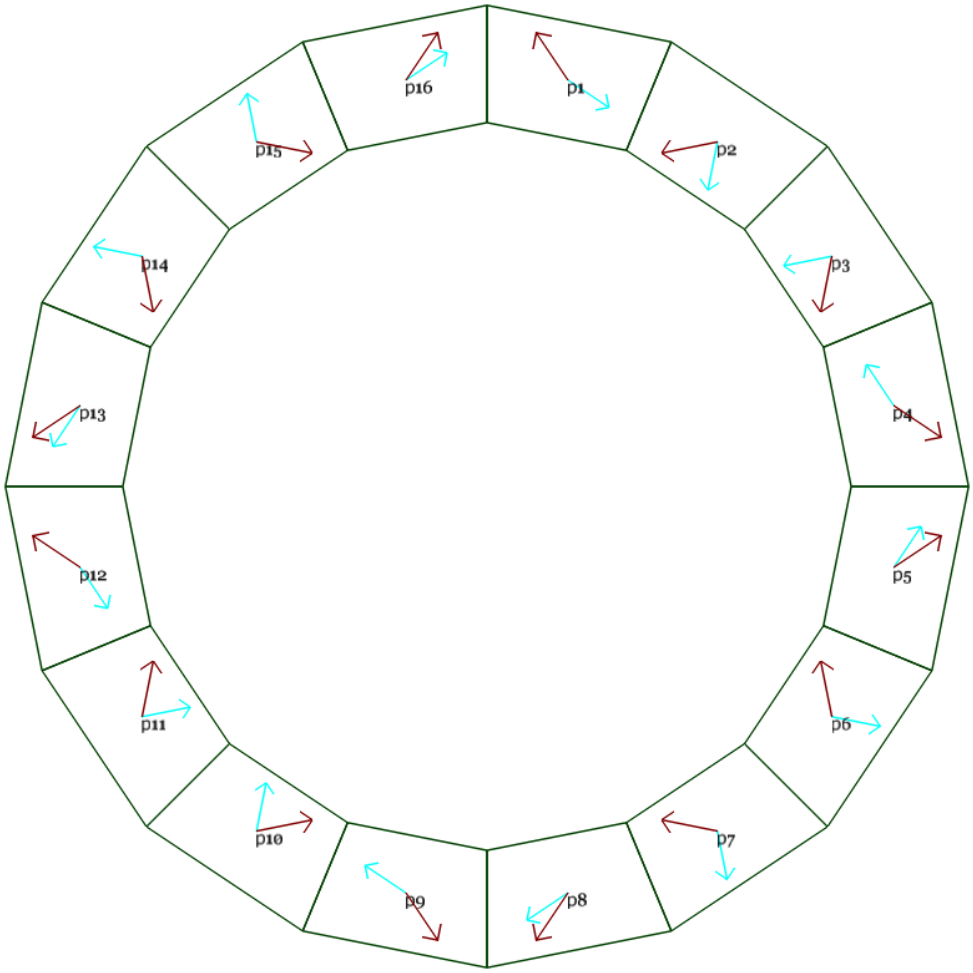
These 2D transverse force calculations were done for the following Halbach magnet types in the CBETA design as it currently stands (an implementation of the April 10, 2017 lattice). These magnets are made out of two longitudinally-stacked layers of permanent magnet blocks.

Magnet Type	Design Version	Magnet length (m)	Block length (m)
QF	v6.5	0.133	0.0665
BD	v6	0.122	0.061
BDT1	v6	0.122	0.061
BDT2	v6	0.122	0.061
QD	v6	0.122	0.061

There is also a QFH ("QF Half") magnet, which is only a single layer of the QF permanent magnet blocks and a BDH magnet which is similarly a single layer of BD. In the 2D approximation, the forces per block in these magnets should be the same as the respective QF and BD magnets but because there is only one layer, total forces e.g. on the aluminium surround will be halved.

2. QF v6.5 Magnet

The picture below shows the transverse forces on each block as vectors (dark red), when the QF magnet is assembled. The light blue arrows are the magnetisation direction.



The pieces are labelled arbitrarily p1-p16 so that the corresponding forces can be written in the table below. For actual block type names from the factory, consult the assembly instructions.

The force can be stated as a force per unit length (Newtons/metre), or a force per block, or for the two blocks constituting the total length of the magnet. The latter gives the force on the outer aluminium shell. (Fx,Fy) force vectors are given in each cell.

Block label in diagram	Force per unit length (N/m)	Force per block (N)	Force per block (lbf)	Force full length (N)	Force full length (lbf)
p1	(-4090,6103)	(-272,406)	(-61.1,91.2)	(-544,812)	(-122.3,182.5)
p2	(-7223,-1447)	(-480,-96)	(-108,-21.6)	(-961,-192)	(-216,-43.3)
p3	(-1447,-7223)	(-96,-480)	(-21.6,-108)	(-192,-961)	(-43.3,-216)
p4	(6103,-4090)	(406,-272)	(91.2,-61.1)	(812,-544)	(182.5,-122.3)
p5	(6103,4090)	(406,272)	(91.2,61.1)	(812,544)	(182.5,122.3)
p6	(-1447,7223)	(-96,480)	(-21.6,108)	(-192,961)	(-43.3,216)
p7	(-7223,1447)	(-480,96)	(-108,21.6)	(-961,192)	(-216,43.3)
p8	(-4090,-6103)	(-272,-406)	(-61.1,-91.2)	(-544,-812)	(-122.3,-182.5)
p9	(4090,-6103)	(272,-406)	(61.1,-91.2)	(544,-812)	(122.3,-182.5)
p10	(7223,1447)	(480,96)	(108,21.6)	(961,192)	(216,43.3)
p11	(1447,7223)	(96,480)	(21.6,108)	(192,961)	(43.3,216)

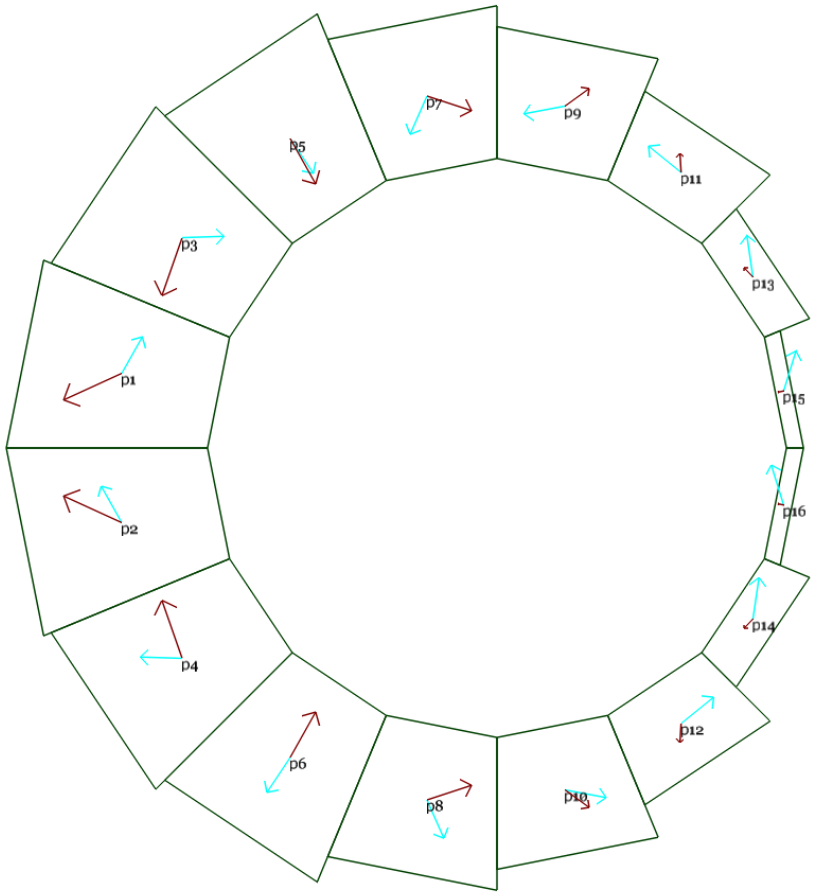
p12	(-6103,4090)	(-406,272)	(-91.2,61.1)	(-812,544)	(-182.5,122.3)
p13	(-6103,-4090)	(-406,-272)	(-91.2,-61.1)	(-812,-544)	(-182.5,-122.3)
p14	(1447,-7223)	(96,-480)	(21.6,-108)	(192,-961)	(43.3,-216)
p15	(7223,-1447)	(480,-96)	(108,-21.6)	(961,-192)	(216,-43.3)
p16	(4090,6103)	(272,406)	(61.1,91.2)	(544,812)	(122.3,182.5)

The magnets will be assembled from two halves, with a vertical split forming a left half and a right half. The table below shows the total force vector on each half when they are in contact.

Subassembly	Force per unit length (N/m)	Force per layer (N)	Force per layer (lbf)	Force full length (N)	Force full length (lbf)
Left half	(13311,0)	(885,0)	(199,0)	(1770,0)	(398,0)
Right half	(-13311,0)	(-885,0)	(-199,0)	(-1770,0)	(-398,0)

3. BD v6 Magnet

The picture below shows the transvers forces on each block as vectors (dark red), when the BD magnet is assembled. The light blue arrows are the magnetisation direction.



The force vectors on each piece of the BD magnet are written in the table below.

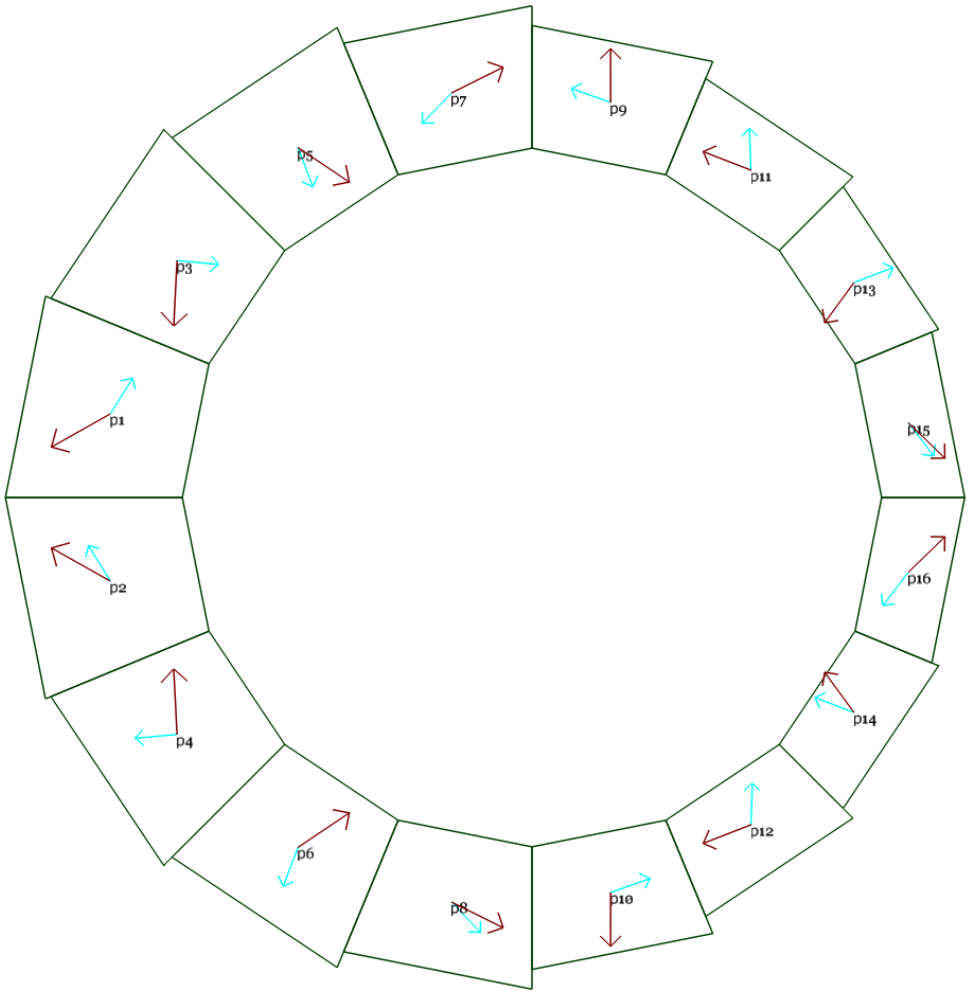
Block label in diagram	Force per unit length (N/m)	Force per block (N)	Force per block (lbf)	Force full length (N)	Force full length (lbf)
p1	(-8842,-4046)	(-539,-247)	(-121.2,-55.5)	(-1079,-494)	(-242.5,-111)
p2	(-8842,4046)	(-539,247)	(-121.2,55.5)	(-1079,494)	(-242.5,111)
p3	(-3086,-8837)	(-188,-539)	(-42.3,-121.2)	(-377,-1078)	(-84.6,-242.4)
p4	(-3086,8837)	(-188,539)	(-42.3,121.2)	(-377,1078)	(-84.6,242.4)
p5	(3882,-6923)	(237,-422)	(53.2,-94.9)	(474,-845)	(106.5,-189.9)
p6	(3882,6923)	(237,422)	(53.2,94.9)	(474,845)	(106.5,189.9)
p7	(6782,-2224)	(414,-136)	(93,-30.5)	(827,-271)	(186,-61)
p8	(6782,2224)	(414,136)	(93,30.5)	(827,271)	(186,61)
p9	(3676,2670)	(224,163)	(50.4,36.6)	(449,326)	(100.8,73.2)
p10	(3676,-2670)	(224,-163)	(50.4,-36.6)	(449,-326)	(100.8,-73.2)
p11	(-172,2917)	(-10,178)	(-2.4,40)	(-21,356)	(-4.7,80)
p12	(-172,-2917)	(-10,-178)	(-2.4,-40)	(-21,-356)	(-4.7,-80)
p13	(-1348,1411)	(-82,86)	(-18.5,19.4)	(-164,172)	(-37,38.7)
p14	(-1348,-1411)	(-82,-86)	(-18.5,-19.4)	(-164,-172)	(-37,-38.7)
p15	(-876,-194)	(-53,-12)	(-12,-2.7)	(-107,-24)	(-24,-5.3)
p16	(-876,194)	(-53,12)	(-12,2.7)	(-107,24)	(-24,5.3)

The table below shows the total force vector on each half of the BD magnet when they are in contact. NB: the forces do not sum to exactly zero due to numerical effects in the simulation.

Subassembly	Force per unit length (N/m)	Force per layer (N)	Force per layer (lbf)	Force full length (N)	Force full length (lbf)
Left half	(-2527,0)	(-154,0)	(-34.7,0)	(-308,0)	(-69.3,0)
Right half	(2561,0)	(156,0)	(35.1,0)	(312,0)	(70.2,0)

4. BDT1 v6 Magnet

The picture below shows the transvers forces on each block as vectors (dark red), when the BDT1 magnet is assembled. The light blue arrows are the magnetisation direction.



The force vectors on each piece of the BDT1 magnet are written in the table below.

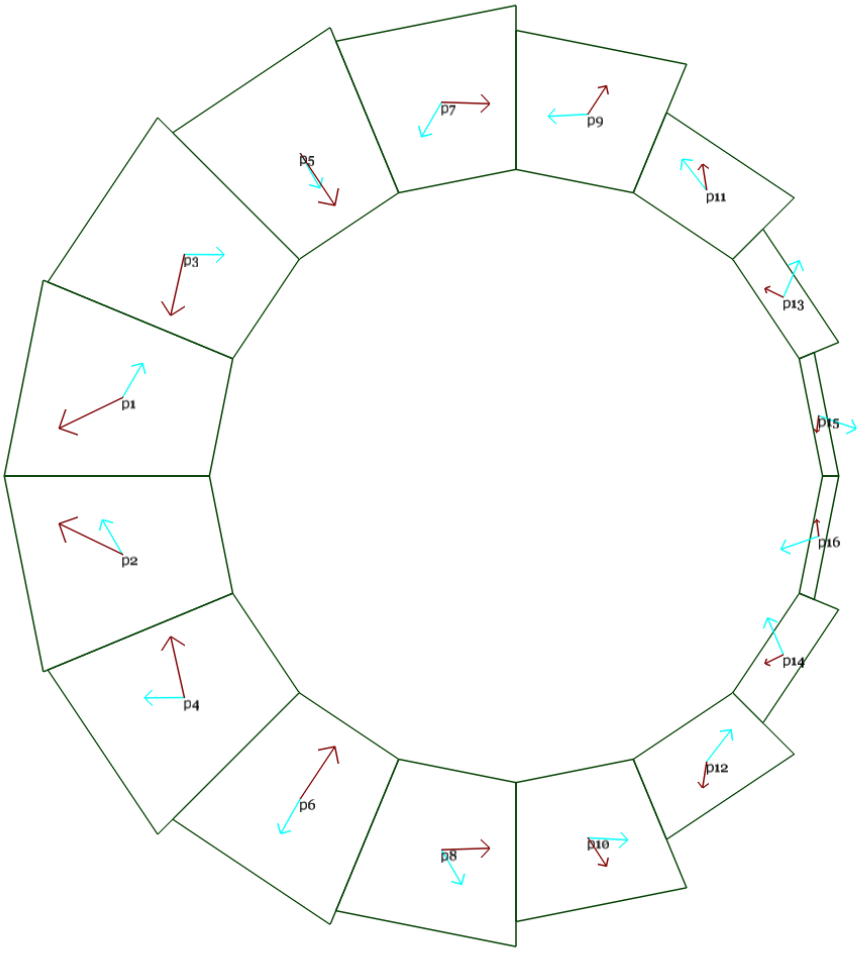
Block label in diagram	Force per unit length (N/m)	Force per block (N)	Force per block (lbf)	Force full length (N)	Force full length (lbf)
p1	(-8989,-5069)	(-548,-309)	(-123.3,-69.5)	(-1097,-618)	(-246.5,-139)
p2	(-8989,5069)	(-548,309)	(-123.3,69.5)	(-1097,618)	(-246.5,139)
p3	(-513,-9986)	(-31,-609)	(-7,-136.9)	(-63,-1218)	(-14.1,-273.9)
p4	(-513,9986)	(-31,609)	(-7,136.9)	(-63,1218)	(-14.1,273.9)
p5	(7798,-5243)	(476,-320)	(106.9,-71.9)	(951,-640)	(213.9,-143.8)
p6	(7798,5243)	(476,320)	(106.9,71.9)	(951,640)	(213.9,143.8)
p7	(7876,3922)	(480,239)	(108,53.8)	(961,479)	(216,107.6)
p8	(7876,-3922)	(480,-239)	(108,-53.8)	(961,-479)	(216,-107.6)
p9	(-11,8205)	(-1,501)	(-0.1,112.5)	(-1,1001)	(-0.3,225)
p10	(-11,-8205)	(-1,-501)	(-0.1,-112.5)	(-1,-1001)	(-0.3,-225)
p11	(-7254,2819)	(-442,172)	(-99.5,38.7)	(-885,344)	(-199,77.3)
p12	(-7254,-2819)	(-442,-172)	(-99.5,-38.7)	(-885,-344)	(-199,-77.3)
p13	(-4462,-6118)	(-272,-373)	(-61.2,-83.9)	(-544,-746)	(-122.4,-167.8)
p14	(-4462,6118)	(-272,373)	(-61.2,83.9)	(-544,746)	(-122.4,167.8)
p15	(5553,-5389)	(339,-329)	(76.1,-73.9)	(677,-658)	(152.3,-147.8)
p16	(5553,5389)	(339,329)	(76.1,73.9)	(677,658)	(152.3,147.8)

The table below shows the total force vector on each half of the BDT1 magnet when they are in contact. NB: the forces do not sum to exactly zero due to numerical effects in the simulation.

Subassembly	Force per unit length (N/m)	Force per layer (N)	Force per layer (lbf)	Force full length (N)	Force full length (lbf)
Left half	(12344,0)	(753,0)	(169.3,0)	(1506,0)	(338.6,0)
Right half	(-12349,0)	(-753,0)	(-169.3,0)	(-1507,0)	(-338.7,0)

5. BDT2 v6 Magnet

The picture below shows the transvers forces on each block as vectors (dark red), when the BDT2 magnet is assembled. The light blue arrows are the magnetisation direction.



The force vectors on each piece of the BDT2 magnet are written in the table below.

Block label in diagram	Force per unit length (N/m)	Force per block (N)	Force per block (lbf)	Force full length (N)	Force full length (lbf)

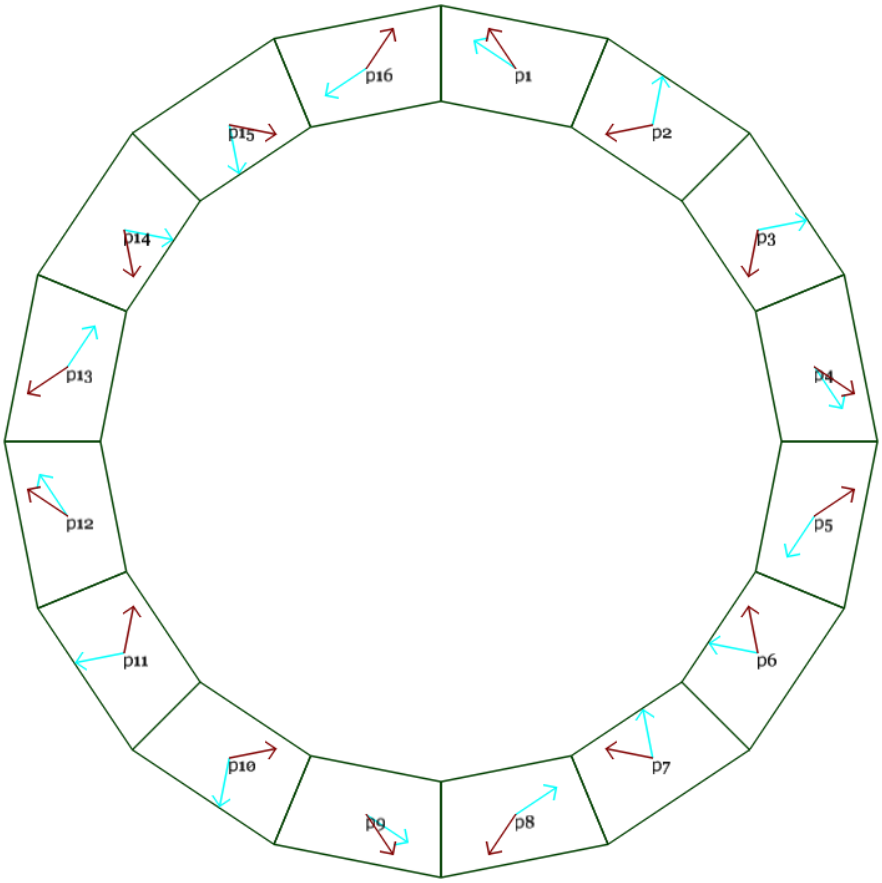
p1	(-10118,-4888)	(-617,-298)	(-138.7,-67)	(-1234,-596)	(-277.5,-134.1)
p2	(-10118,4888)	(-617,298)	(-138.7,67)	(-1234,596)	(-277.5,134.1)
p3	(-2197,-9771)	(-134,-596)	(-30.1,-134)	(-268,-1192)	(-60.3,-268)
p4	(-2197,9771)	(-134,596)	(-30.1,134)	(-268,1192)	(-60.3,268)
p5	(5551,-8360)	(339,-510)	(76.1,-114.6)	(677,-1020)	(152.2,-229.3)
p6	(5551,8360)	(339,510)	(76.1,114.6)	(677,1020)	(152.2,229.3)
p7	(7709,-246)	(470,-15)	(105.7,-3.4)	(940,-30)	(211.4,-6.7)
p8	(7709,246)	(470,15)	(105.7,3.4)	(940,30)	(211.4,6.7)
p9	(2943,4511)	(180,275)	(40.4,61.9)	(359,550)	(80.7,123.7)
p10	(2943,-4511)	(180,-275)	(40.4,-61.9)	(359,-550)	(80.7,-123.7)
p11	(-669,4258)	(-41,260)	(-9.2,58.4)	(-82,519)	(-18.3,116.8)
p12	(-669,-4258)	(-41,-260)	(-9.2,-58.4)	(-82,-519)	(-18.3,-116.8)
p13	(-2945,1443)	(-180,88)	(-40.4,19.8)	(-359,176)	(-80.8,39.6)
p14	(-2945,-1443)	(-180,-88)	(-40.4,-19.8)	(-359,-176)	(-80.8,-39.6)
p15	(-335,-2617)	(-20,-160)	(-4.6,-35.9)	(-41,-319)	(-9.2,-71.8)
p16	(-335,2617)	(-20,160)	(-4.6,35.9)	(-41,319)	(-9.2,71.8)

The table below shows the total force vector on each half of the BDT2 magnet when they are in contact. NB: the forces do not sum to exactly zero due to numerical effects in the simulation.

Subassembly	Force per unit length (N/m)	Force per layer (N)	Force per layer (lbf)	Force full length (N)	Force full length (lbf)
Left half	(1889,0)	(115,0)	(25.9,0)	(231,0)	(51.8,0)
Right half	(-2012,0)	(-123,0)	(-27.6,0)	(-245,0)	(-55.2,0)

6. QD v6 Magnet

The picture below shows the transvers forces on each block as vectors (dark red), when the QD magnet is assembled. The light blue arrows are the magnetisation direction.



The force vectors on each piece of the QD magnet are written in the table below.

Block label in diagram	Force per unit length (N/m)	Force per block (N)	Force per block (lbf)	Force full length (N)	Force full length (lbf)
p1	(-3401,5074)	(-207,309)	(-46.6,69.6)	(-415,619)	(-93.3,139.2)
p2	(-6006,-1204)	(-366,-73)	(-82.4,-16.5)	(-733,-147)	(-164.7,-33)
p3	(-1204,-6006)	(-73,-366)	(-16.5,-82.4)	(-147,-733)	(-33,-164.7)
p4	(5074,-3401)	(309,-207)	(69.6,-46.6)	(619,-415)	(139.2,-93.3)
p5	(5074,3401)	(309,207)	(69.6,46.6)	(619,415)	(139.2,93.3)
p6	(-1204,6006)	(-73,366)	(-16.5,82.4)	(-147,733)	(-33,164.7)
p7	(-6006,1204)	(-366,73)	(-82.4,16.5)	(-733,147)	(-164.7,33)
p8	(-3401,-5074)	(-207,-309)	(-46.6,-69.6)	(-415,-619)	(-93.3,-139.2)
p9	(3401,-5074)	(207,-309)	(46.6,-69.6)	(415,-619)	(93.3,-139.2)
p10	(6006,1204)	(366,73)	(82.4,16.5)	(733,147)	(164.7,33)
p11	(1204,6006)	(73,366)	(16.5,82.4)	(147,733)	(33,164.7)
p12	(-5074,3401)	(-309,207)	(-69.6,46.6)	(-619,415)	(-139.2,93.3)
p13	(-5074,-3401)	(-309,-207)	(-69.6,-46.6)	(-619,-415)	(-139.2,-93.3)
p14	(1204,-6006)	(73,-366)	(16.5,-82.4)	(147,-733)	(33,-164.7)
p15	(6006,-1204)	(366,-73)	(82.4,-16.5)	(733,-147)	(164.7,-33)
p16	(3401,5074)	(207,309)	(46.6,69.6)	(415,619)	(93.3,139.2)

The table below shows the total force vector on each half of the QD magnet when they are in contact.

Subassembly	Force per unit length (N/m)	Force per layer (N)	Force per layer (lbf)	Force full length (N)	Force full length (lbf)
Left half	(11075,0)	(676,0)	(151.9,0)	(1351,0)	(303.7,0)
Right half	(-11075,0)	(-676,0)	(-151.9,0)	(-1351,0)	(-303.7,0)