IT quadrupoles: summary of test results

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on behalf of the MQXF collaboration

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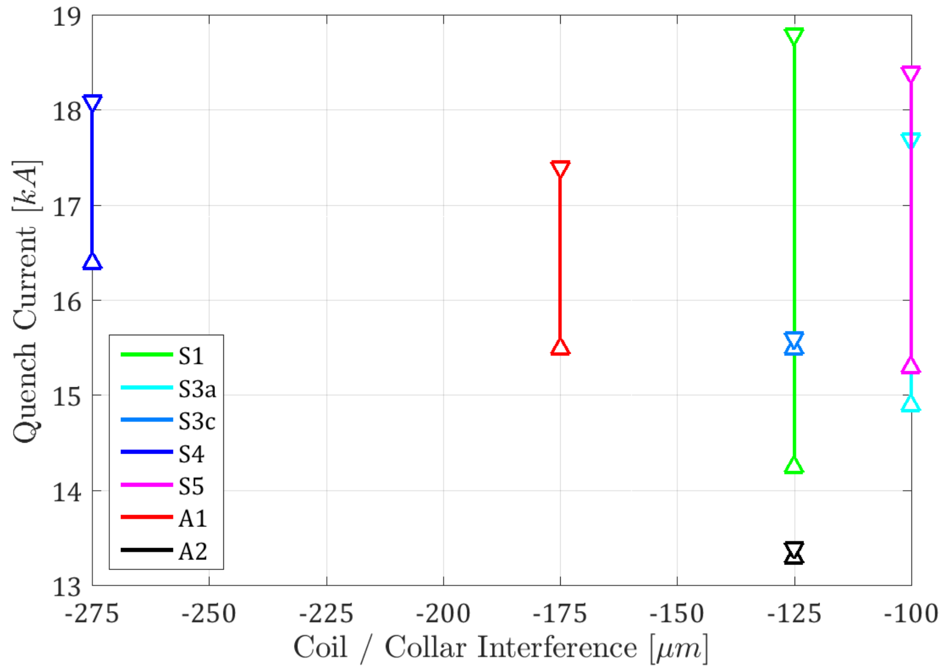
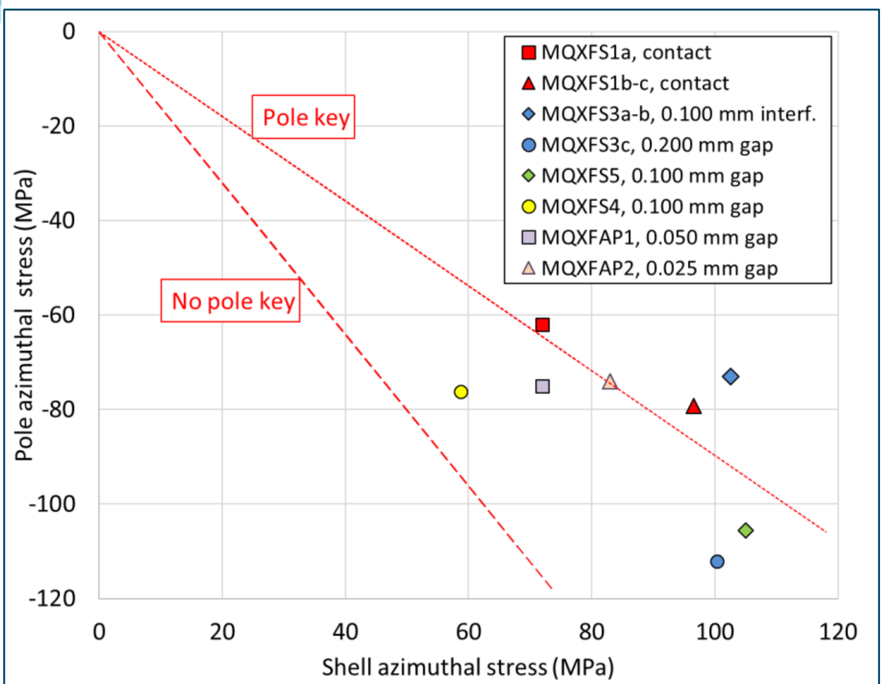
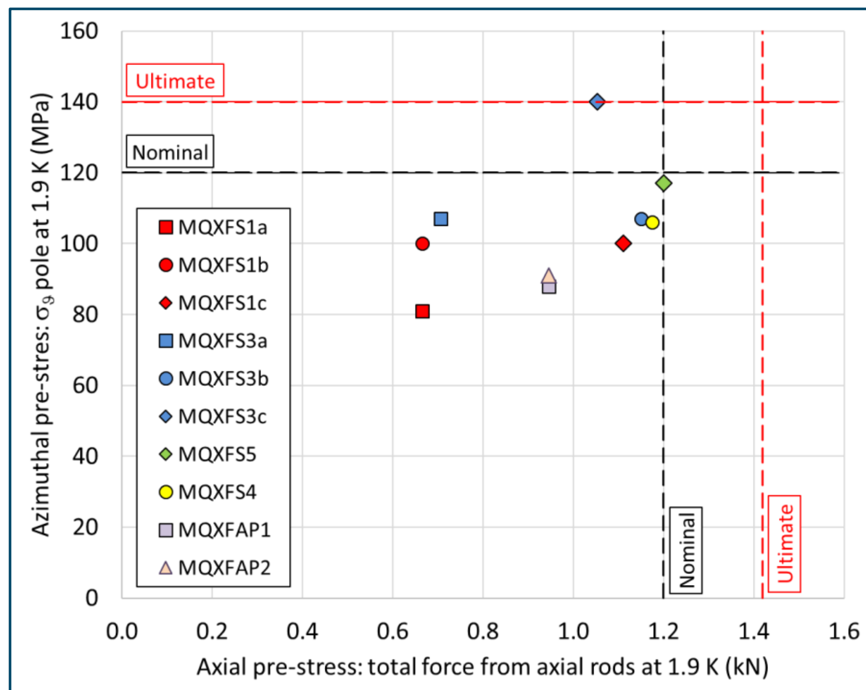
CERN

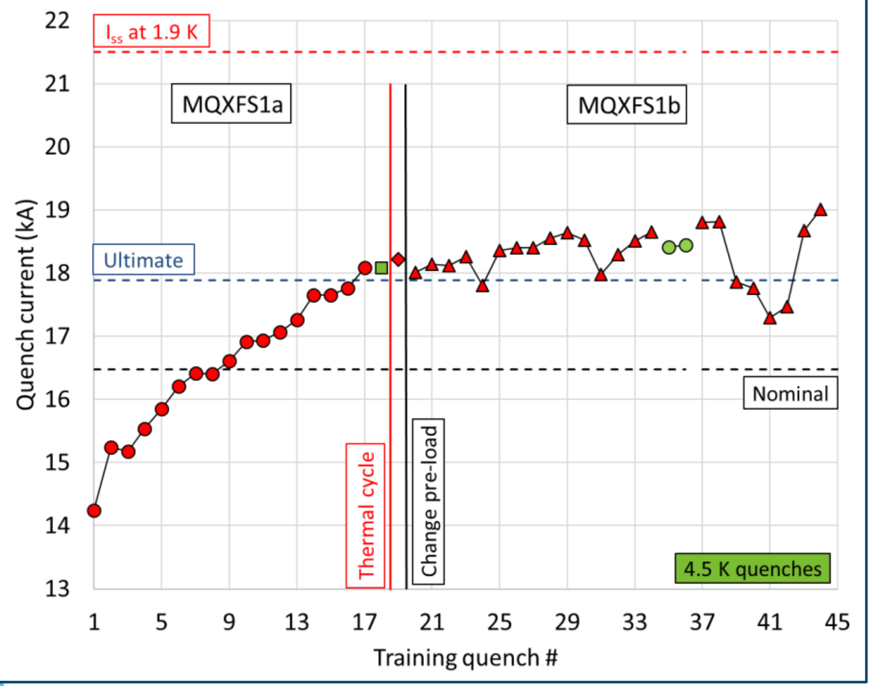
Acknowledgments

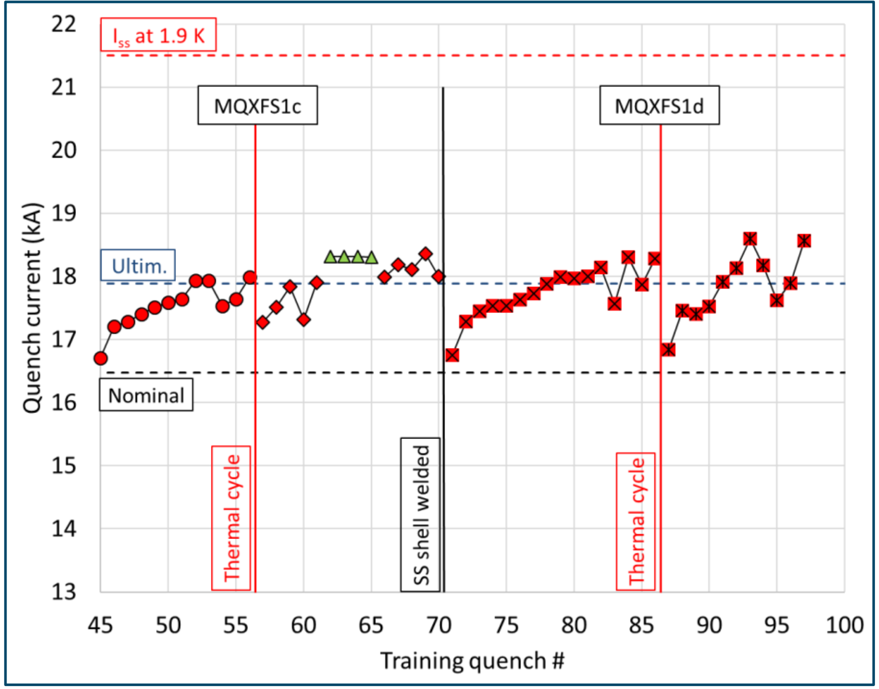
- CERN
  - A. Ballarino, H. Bajas, M. Bajko, B. Bordini, N. Bourcey, J.C. Perez, S. Izquierdo Bermudez, S. Ferradas Troitino, L. Fiscarelli, J. Fleiter, M. Guinchard, O. Housiaux, F. Lackner, F. Mangiarotti, A. Milanese, P. Moyret, H. Prin, R. Principe, E. Ravaioli, T. Sahner, S. Sequeira Tavares, E. Takala, E. Todesco, G. Vallone
- BNL
  - M. Anerella, P. Joshi, J. Muratore, J. Schmalzle, P. Wanderer
- FNAL
  - G. Ambrosio, M. Baldini, J. Blowers, R. Bossert, G. Chlachidze, L. Cooley, S. Krave, F. Nobrega, V. Marinozzi, I. Novitsky, C. Santini, S. Stoynev, T. Strauss, M. Yu
- LBNL
  - D. Cheng, M. Marchevsky, H. Pan, I. Pong, S. Prestemon, G. Sabbi, X. Wang
- NHMFL
  - Lance Cooley

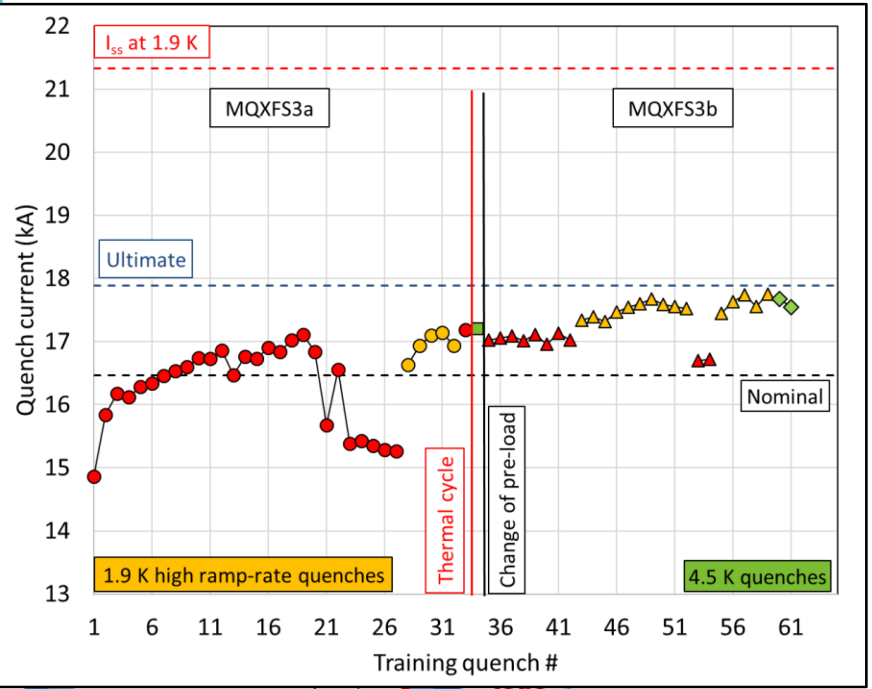

Quench Current [kA]
Coil / Collar Interference [μm]
S1
S3a
S3c
S4
S5
A1
A2

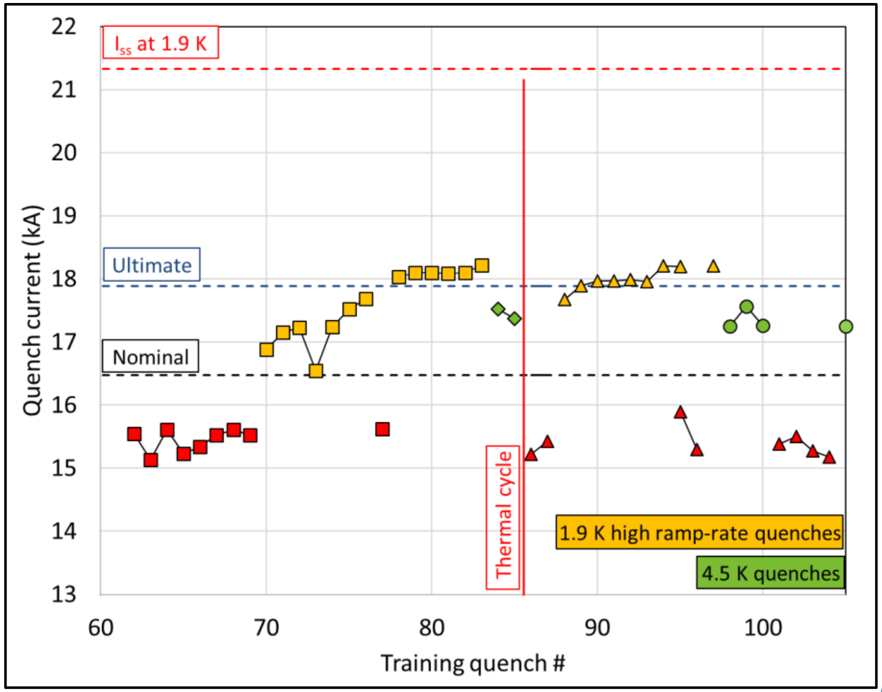

Pole azimuthal stress (MPa)
Shell azimuthal stress (MPa)
Pole key
No pole key
MQXFS1a, contact
MQXFS1b-c, contact
MQXFS3a-b, 0.100 mm interf.
MQXFS3c, 0.200 mm gap
MQXFS5, 0.100 mm gap
MQXFS4, 0.100 mm gap
MQXFAP1, 0.050 mm gap
MQXFAP2, 0.025 mm gap


Azimuthal pre-stres: σθ pole at 1.9 K (MPa)
Axial pre-stress: total force from axial rods at 1.9 K (kN)
Ultimate
Nominal
MQXFS1a
MQXFS1b
MQXFS1c
MQXFS3a
MQXFS3b
MQXFS3c
MQXFS5
MQXFS4
MQXFAP1
MQXFAP2
Nominal
Ultimate


Iss at 1.9 K
MQXFS1a
MQXFS1b
Ultimate
Nominal
Thermal cycle
Change pre-load
4.5 K quenches
Quench current (kA)
Training quench #


Iss at 1.9 K
MQXFS1c
MQXFS1d
Ultim.
Nominal
Thermal cycle
SS shell welded
Thermal cycle
Quench current (kA)
Training quench #

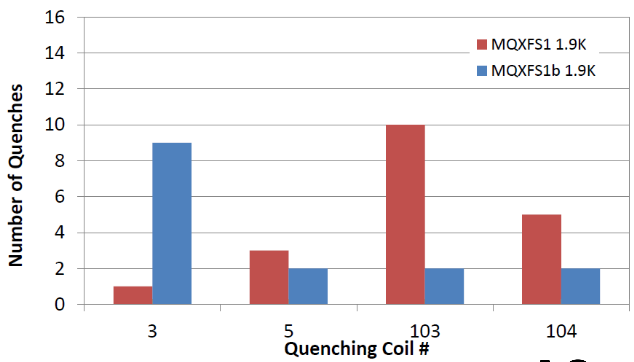

Iss at 1.9 K
MQXFS3a
MQXFS3b
Ultimate
Nominal
Thermal cycle
Change of pre-load
1.9 K high ramp-rate quenches
4.5 K quenches
Quench current (kA)
Training quench #

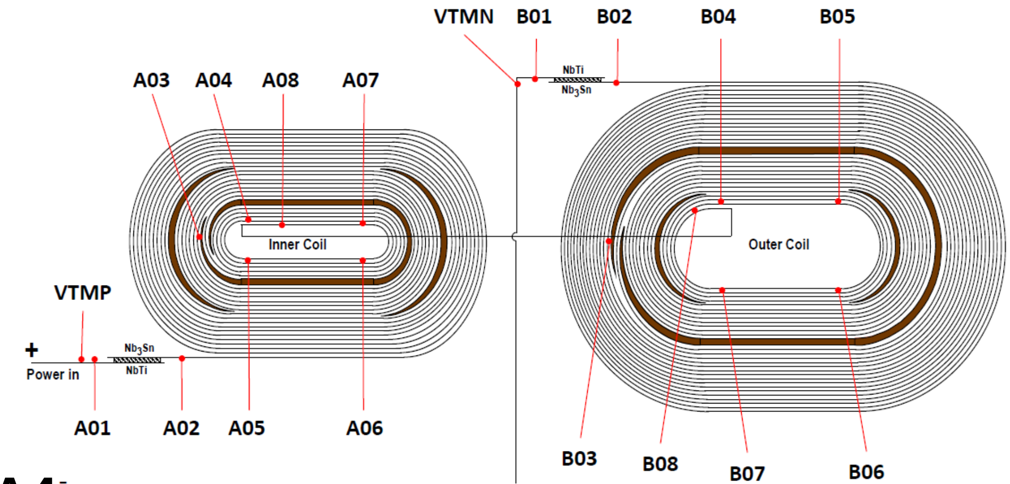

Iss at 1.9 K
Ultimate
Nominal
Thermal cycle
1.9 K high ramp-rate quenches
4.5 K quenches
Quench current (kA)
Training quench #

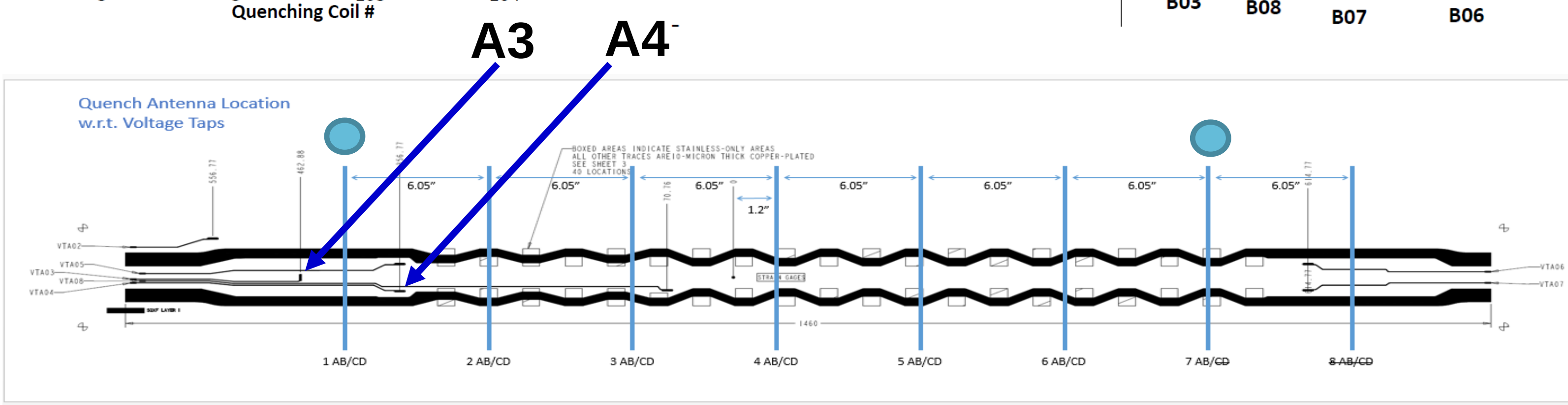
Quench Locations

Most quenches developed in the IL Pole block A3-A4 segment

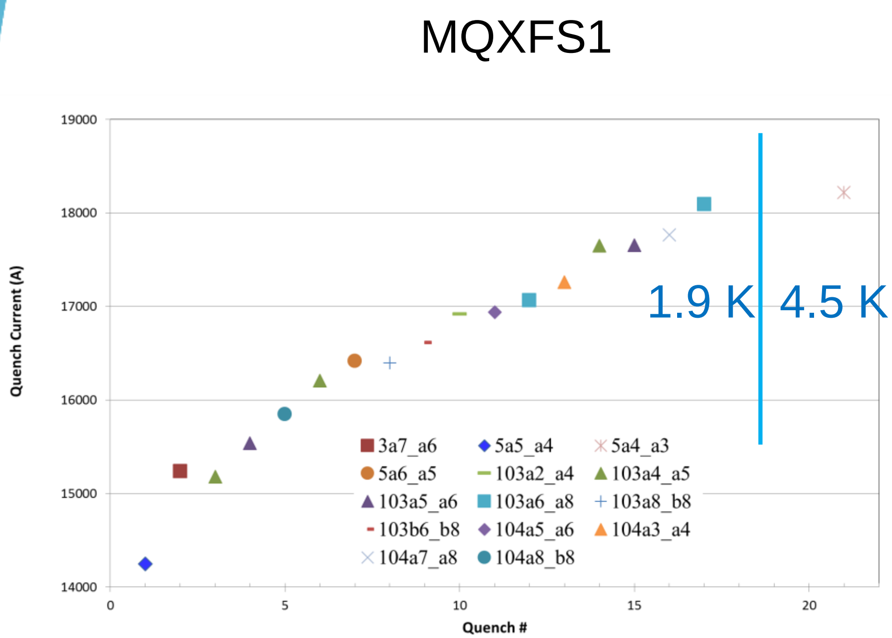
- QA: LE, QA segment #1 (11 quenches) and
  RE, QA segment #7 (4)

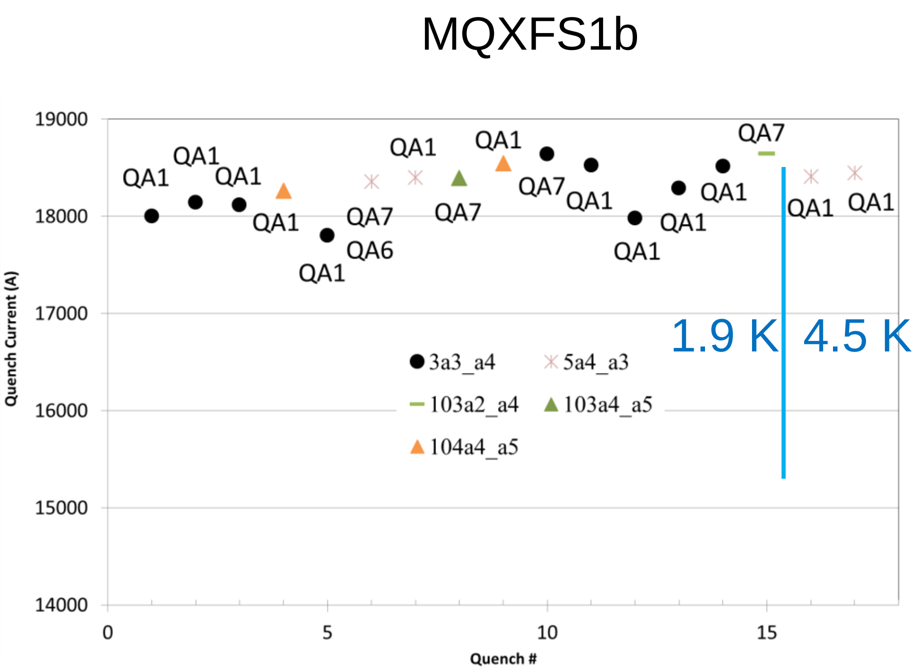






Quench Locations





Almost all quenches in this test are in the magnet ends (13 out of 17 in the Lead End).

The two quenches with large detraining and the first three quenches in the tests were in an area (and coil) that did not quench in the first test

MQXFS1c

MQXFS1c	23/05/2017	1.9	52	45	42	20	50to11; 20toQ	16705	16.705	21.5	169.1	14.6	78	60	134.4	11.6	Coil 3, A3A4
MQXFS1c	24/05/2017	1.9	53	46	43	20	50to11; 20toQ	17213	17.213	21.5	169.1	14.6	80	64	138.2	11.9	Coil 3, A3A4
MQXFS1c	24/05/2017	1.9	54	47	44	20	50to11; 20toQ	17288	17.288	21.5	169.1	14.6	80	65	138.7	11.9	Coil 3, A3A4
MQXFS1c	24/05/2017	1.9	55	48	45	20	50to11; 20toQ	17408	17.408	21.5	169.1	14.6	81	66	139.6	12.0	Coil 3, A3A4
MQXFS1c	24/05/2017	1.9	56	49	46	20	50to11; 20toQ	17507	17.507	21.5	169.1	14.6	81	66	140.3	12.1	Coil 3, A3A4
MQXFS1c	25/05/2017	1.9	57	50	47	20	50to11; 20toQ	17583	17.583	21.5	169.1	14.6	82	67	140.9	12.1	Coil 3, A3A4
MQXFS1c	25/05/2017	1.9	58	51	48	20	50to11; 20toQ	17643	17.643	21.5	169.1	14.6	82	67	141.3	12.2	Coil 3, A3A4
MQXFS1c	26/05/2017	1.9	59	52	49	20	50to11; 20toQ	17934	17.934	21.5	169.1	14.6	83	70	143.4	12.4	Coil 104, A5A6
MQXFS1c	30/05/2017	1.9	60	53	50	20	50to11; 20toQ	17930	17.93	21.5	169.1	14.6	83	70	143.4	12.4	Coil 3, A3A4
MQXFS1c	30/05/2017	1.9	61	54	51	20	50to11; 20toQ	17530	17.53	21.5	169.1	14.6	82	66	140.5	12.1	Coil 3, A3A4
MQXFS1c	30/05/2017	1.9	62	55	52	20	50to11; 20toQ	17641	17.641	21.5	169.1	14.6	82	67	141.3	12.2	Coil 3, A3A4
MQXFS1c	30/05/2017	1.9	63	56	53	20	50to11; 20toQ	17992	17.992	21.5	169.1	14.6	84	70	143.9	12.4	Coil 3, A3A4
MQXFS1c	21/06/2017	1.9	64	57	54	20	50to11; 20toQ	17276	17.276	21.5	169.1	14.6	80	65	138.6	11.9	Coil 3, A3A4
MQXFS1c	21/06/2017	1.9	65	58	55	20	50to11; 20toQ	17508	17.508	21.5	169.1	14.6	81	66	140.3	12.1	Coil 3, A3A4
MQXFS1c	22/06/2017	1.9	66	59	56	20	50to11; 20toQ	17839	17.839	21.5	169.1	14.6	83	69	142.7	12.3	Coil 3, A3A4
MQXFS1c	22/06/2017	1.9	67	60	57	20	50to11; 20toQ	17320	17.32	21.5	169.1	14.6	81	65	138.9	12.0	Coil 3, A3A4
MQXFS1c	22/06/2017	1.9	68	61	58	20	50to11; 20toQ	17904	17.904	21.5	169.1	14.6	83	69	143.2	12.3	Coil 3, A3A4
MQXFS1c	23/06/2017	4.5	69	62		20	50to11; 20toQ	18320	18.32	19.6	155.2	13.4	94	88	146.3	12.6	Coil 5, A3A4
MQXFS1c	23/06/2017	4.5	70	63		20	50to11; 20toQ	18316	18.316	19.6	155.2	13.4	94	88	146.2	12.6	Coil 5, A3A4
MQXFS1c	23/06/2017	4.5	71	64		20	50to11; 20toQ	18315	18.315	19.6	155.2	13.4	94	88	146.2	12.6	Coil 5, A3A4
MQXFS1c	23/06/2017	4.5	72	65		20	50to11; 20toQ	18307	18.307	19.6	155.2	13.4	94	88	146.2	12.6	Coil 5, A3A4
MQXFS1c	26/06/2017	1.9	73	66	59	20	50to11; 20toQ	17988	17.988	21.5	169.1	14.6	84	70	143.8	12.4	Coil 5, A3A4
MQXFS1c	26/06/2017	1.9	74	67	60	20	50to11; 20toQ	18186	18.186	19.6	155.2	13.4	93	87	145.3	12.5	Coil 3, A3A4
MQXFS1c	26/06/2017	1.9	75	68	61	20	50to11; 20toQ	18106	18.106	19.6	155.2	13.4	93	86	144.7	12.5	Coil 3, A3A4
MQXFS1c	28/06/2017	1.9	76	69	62	20	50to11; 20toQ	18360	18.36	19.6	155.2	13.4	94	88	146.5	12.6	Coil 5, A3A4

MQXFS1d

MQXFS1d	24/04/2018	1.9	78	71	64	20	50to11; 20toQ	16756	16.756	21.5	169.1	14.6	78	61	134.8	11.6	3a4_a3
MQXFS1d	24/04/2018	1.9	79	72	65	20	50to11; 20toQ	17288	17.288	21.5	169.1	14.6	80	65	138.7	11.9	3a4_a3
MQXFS1d	25/04/2018	1.9	80	73	66	20	50to11; 20toQ	17451	17.451	21.5	169.1	14.6	81	66	139.9	12.1	3a4_a3
MQXFS1d	25/04/2018	1.9	81	74	67	20	50to11; 20toQ	17529	17.529	21.5	169.1	14.6	82	66	140.5	12.1	3a4_a3
MQXFS1d	25/04/2018	1.9	82	75	68	20	50to11; 20toQ	17534	17.534	21.5	169.1	14.6	82	67	140.5	12.1	3a4_a3
MQXFS1d	26/04/2018	1.9	83	76	69	20	50to11; 20toQ	17632	17.632	21.5	169.1	14.6	82	67	141.2	12.2	104/IL
MQXFS1d	26/04/2018	1.9	84	77	70	20	50to11; 20toQ	17727	17.727	21.5	169.1	14.6	82	68	141.9	12.2	5a4_a3
MQXFS1d	26/04/2018	1.9	85	78	71	20	50to11; 20toQ	17881	17.881	21.5	169.1	14.6	83	69	143.1	12.3	3a4_a3
MQXFS1d	26/04/2018	1.9	86	79	72	20	50to11; 20toQ	17991	17.991	21.5	169.1	14.6	84	70	143.9	12.4	
MQXFS1d	27/04/2018	1.9	87	80	73	20	50to11; 20toQ	17970	17.97	21.5	169.1	14.6	84	70	143.7	12.4	5a4_a3
MQXFS1d	27/04/2018	1.9	88	81	74	20	50to11; 20toQ	17998	17.998	21.5	169.1	14.6	84	70	143.9	12.4	3a3_a3
MQXFS1d	27/04/2018	1.9	89	82	75	20	50to11; 20toQ	18138	18.138	21.5	169.1	14.6	84	71	144.9	12.5	104/IL
MQXFS1d	27/04/2018	1.9	90	83	76	20	50to11; 20toQ	17565	17.565	21.5	169.1	14.6	82	67	140.7	12.1	5a5_a4
MQXFS1d	01/05/2018	1.9	91	84	77	20	50to11; 20toQ	18300	18.3	21.5	169.1	14.6	85	72	146.1	12.6	3a4_a3
MQXFS1d	02/05/2018	1.9	92	85	78	20	50to11; 20toQ	17870	17.87	21.5	169.1	14.6	83	69	143.0	12.3	5a4_a3
MQXFS1d	03/05/2018	1.9	93	86	79	20	50to11; 20toQ	18288	18.288	21.5	169.1	14.6	85	72	146.0	12.6	5A4_A35
MQXFS1d 2t	24/05/2018	1.9	94	87	80	20	50to11; 20toQ	16840	16.84	21.5	169.1	14.6	78	61	135.4	11.7	3a4_a3
MQXFS1d 2t	25/05/2018	1.9	95	88	81	20	50to11; 20toQ	17462	17.462	21.5	169.1	14.6	81	66	140.0	12.1	3a4_a3
MQXFS1d 2t	25/05/2018	1.9	96	89	82	20	50to11; 20toQ	17407	17.407	21.5	169.1	14.6	81	66	139.6	12.0	5a4_a3
MQXFS1d 2t	25/05/2018	1.9	97	90	83	20	50to11; 20toQ	17526	17.526	21.5	169.1	14.6	82	66	140.5	12.1	5a4_a3
MQXFS1d 2t	29/05/2018	1.9	98	91	84	20	50to11; 20toQ	17912	17.912	21.5	169.1	14.6	83	69	143.3	12.3	5a4_a3
MQXFS1d 2t	29/05/2018	1.9	99	92	85	20	50to11; 20toQ	18131	18.131	21.5	169.1	14.6	84	71	144.9	12.5	3a4_a3
MQXFS1d 2t	29/05/2018	1.9	100	93	86	20	50to11; 20toQ	18600	18.6	21.5	169.1	14.6	87	75	148.3	12.8	5a4_a3
MQXFS1d 2t	31/05/2018	1.9	101	94	87	20	50to11; 20toQ	18170	18.17	21.5	169.1	14.6	85	71	145.2	12.5	5a4_a3
MQXFS1d 2t	31/05/2018	1.9	102	95	88	20	50to11; 20toQ	17616	17.616	21.5	169.1	14.6	82	67	141.1	12.2	3a4_a3
MQXFS1d 2t	04/06/2018	1.9	103	96	89	20	50to11; 20toQ	17896	17.896	21.5	169.1	14.6	83	69	143.2	12.3	3a4_a3
MQXFS1d 2t	04/06/2018	1.9	104	97	90	20	50to11; 20toQ	18560	18.56	21.5	169.1	14.6	86	75	148.0	12.8	3a4_a4

MQXFS3a

MQXFS3	13/10/2016	2.0	1	1	20	50to10; 20toQ	14867	14.867	21.3	168.754	14.550	70	49	120.6	10.4	Coil 7, I5-I6
MQXFS3	13/10/2016	2.0	2	2	20	50to10; 20toQ	15846	15.846	21.3	168.754	14.550	74	55	127.9	11.0	Coil 107, I3-I4
MQXFS3	14/10/2016	2.1	3	3	20	50to10; 20toQ	16174	16.174	21.3	168.754	14.550	76	57	130.4	11.2	Coil 105, O2O3
MQXFS3	14/10/2016	2.1	4	4	20	50to10; 20toQ	16120	16.120	21.3	168.754	14.550	76	57	130.0	11.2	Coil 105, I7I8
MQXFS3	14/10/2016	2.1	5	5	20	50to10; 20toQ	16281	16.281	21.3	168.754	14.550	76	58	131.2	11.3	Coil 105, I3-I4
MQXFS3	14/10/2016	2.1	6	6	20	50to10; 20toQ	16341	16.341	21.3	168.754	14.550	77	59	131.6	11.3	Coil 105, I3-I4
MQXFS3	17/10/2016	2.1	7	7	20	50to10; 20toQ	16463	16.463	21.3	168.754	14.550	77	60	132.5	11.4	Coil 105, I8-I7
MQXFS3	17/10/2016	2.1	8	8	20	50to10; 20toQ	16537	16.537	21.3	168.754	14.550	78	60	133.1	11.5	Coil 105, I3-I4
MQXFS3	17/10/2016	2.1	9	9	20	50to10; 20toQ	16603	16.603	21.3	168.754	14.550	78	61	133.6	11.5	Coil 105, I3-I4
MQXFS3	17/10/2016	2.1	10	10	20	50to10; 20toQ	16739	16.739	21.3	168.754	14.550	78	62	134.6	11.6	Coil 106, I3-I4
MQXFS3	17/10/2016	2.1	11	11	20	50to10; 20toQ	16735	16.735	21.3	168.754	14.550	78	62	134.6	11.6	Coil 105, I7-I6
MQXFS3	21/10/2016	2.1	12	12	20	50to10; 20toQ	16856	16.856	21.3	168.754	14.550	79	62	135.5	11.7	Coil 106, O3O2
MQXFS3	21/10/2016	2.1	13	13	20	50to10; 20toQ	16467	16.467	21.3	168.754	14.550	77	60	132.6	11.4	Coil 105, I7I8
MQXFS3	24/10/2016	2.1	14	14	20	50to10; 20toQ	16762	16.762	21.3	168.754	14.550	79	62	134.8	11.6	Coil 105, I7I8
MQXFS3	24/10/2016	2.1	15	15	20	50to10; 20toQ	16732	16.732	21.3	168.754	14.550	78	62	134.5	11.6	Coil 105, I7I8
MQXFS3	24/10/2016	2.1	16	16	20	50to10; 20toQ	16907	16.907	21.3	168.754	14.550	79	63	135.8	11.7	Coil 105, I3-I4
MQXFS3	25/10/2016	2.1	17	17	20	50to10; 20toQ	16839	16.839	21.3	168.754	14.550	79	62	135.3	11.7	Coil 105, I7I8
MQXFS3	25/10/2016	2.1	18	18	20	50to10; 20toQ	17025	17.025	21.3	168.754	14.550	80	64	136.7	11.8	Coil 106, I6I5
MQXFS3	25/10/2016	2.1	19	19	20	50to10; 20toQ	17109	17.109	21.3	168.754	14.550	80	64	137.3	11.8	Coil 7, I5-I6
MQXFS3	26/10/2016	2.1	20	20	20	50to10; 20toQ	16838	16.838	21.3	168.754	14.550	79	62	135.3	11.7	Coil 7, I3I4
MQXFS3	26/10/2016	2.1	21	21	20	50to10; 20toQ	15683	15.683	21.3	168.754	14.550	74	54	126.7	10.9	Coil 7, I3I4
MQXFS3	26/10/2016	2.1	22	22	20	50to10; 20toQ	16559	16.559	21.3	168.754	14.550	78	60	133.2	11.5	Coil 7, I3I4
MQXFS3	26/10/2016	2.1	23	23	20	50to10; 20toQ	15384	15.384	21.3	168.754	14.550	72	52	124.5	10.7	Coil 7, I3I4
MQXFS3	27/10/2016	2.1	24	24	20	50to10; 20toQ	15429	15.429	21.3	168.754	14.550	72	52	124.8	10.7	Coil 7, I3I4
MQXFS3	27/10/2016	2.1	25	25	20	50to10; 20toQ	15352	15.352	21.3	168.754	14.550	72	52	124.2	10.7	Coil 7, I3I4
MQXFS3	27/10/2016	2.1	26	26	20	50to10; 20toQ	15288	15.288	21.3	168.754	14.550	72	51	123.7	10.7	Coil 7, I3I4
MQXFS3	31/10/2016	2.1	27		350	350toQ	16250	16.25	21.3	168.754	14.550	76	58	130.9	11.3	Coil 107, O4O5
MQXFS3	31/10/2016	2.1	28		400	400toQ	14190	14.19	21.3	168.754	14.550	67	44	115.5	9.9	Coil7, I2I3
MQXFS3	31/10/2016	2.1	29	27	20	50to10; 20toQ	15269	15.269	21.3	168.754	14.550	72	51	123.6	10.6	Coil 7, I3I4
MQXFS3	01/11/2016	2.1	30	28	300	300toQ	16632	16.632	21.3	168.754	14.550	78	61	133.8	11.5	Coil 105, O2O3
MQXFS3	01/11/2016	2.1	31	29	200	200toQ	16934	16.934	21.3	168.754	14.550	79	63	136.0	11.7	Coil 107, O3O$
MQXFS3	01/11/2016	2.1	32	30	100	100toQ	17099	17.099	21.3	168.754	14.550	80	64	137.3	11.8	Coil 7, I3I4
MQXFS3	01/11/2016	2.1	33	31	50	50toQ	17140	17.14	21.3	168.754	14.550	80	65	137.6	11.9	Coil 7, I3I4
MQXFS3	01/11/2016	2.1	34	32	50	50toQ	16936	16.936	21.3	168.754	14.550	79	63	136.0	11.7	Coil 105, O2O3
MQXFS3	01/11/2016	2.1	35	33	20	50to10; 20toQ	17189	17.189	21.3	168.754	14.550	81	65	137.9	11.9	Coil 105, I5-I6
MQXFS3	03/11/2016	4.3	36	34	20	50to10; 20toQ	17205	17.205	19.4	154.4	13.3	89	79	138.1	11.9	Coil 105, I8O17

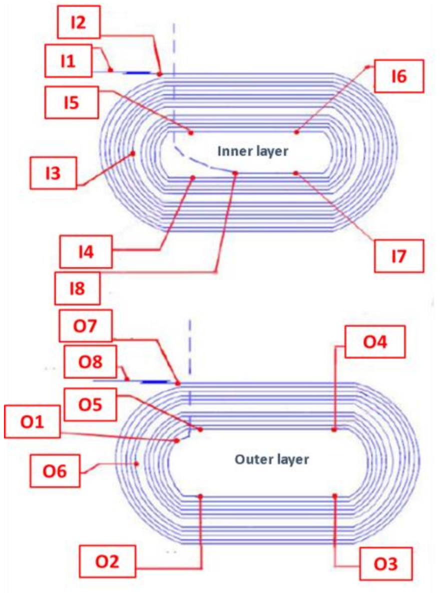
MQXFS3b

MQXFS3b	30/11/2016	1.9	37	35	20	50to10; 20toQ	17028	17.028	21.3	168.754	14.550	80	64	136.7	11.8	Coil 105, I3-I6
MQXFS3b	30/11/2016	1.9	38	36	20	50to10; 20toQ	17054	17.054	21.3	168.754	14.550	80	64	136.9	11.8	Coil 7, I3-I4
MQXFS3b	01/12/2016	1.9	39	37	20	50to10; 20toQ	17090	17.09	21.3	168.754	14.550	80	64	137.2	11.8	Coil 7, I3-I4
MQXFS3b	01/12/2016	1.9	40	38	20	50to10; 20toQ	17012	17.012	21.3	168.754	14.550	80	64	136.6	11.8	Coil 7, I3-I4
MQXFS3b	01/12/2016	1.9	41	39	20	50to10; 20toQ	17110	17.11	21.3	168.754	14.550	80	64	137.3	11.8	Coil 7, I3-I4
MQXFS3b	01/12/2016	1.9	42	40	20	50to10; 20toQ	16955	16.955	21.3	168.754	14.550	79	63	136.2	11.7	Coil 105, I3-I6
MQXFS3b	01/12/2016	1.9	43	41	20	50to10; 20toQ	17137	17.137	21.3	168.754	14.550	80	65	137.5	11.9	Coil 105, I3-I6
MQXFS3b	02/12/2016	1.9	44	42	20	50to10; 20toQ	17019	17.019	21.3	168.754	14.550	80	64	136.7	11.8	Coil 105, I3-I6
MQXFS3b	02/12/2016	1.9	45	43	300	300toQ	17344	17.344	21.3	168.754	14.550	81	66	139.1	12.0	Coil 107, I8-O1
MQXFS3b	05/12/2016	1.9	46	44	300	50to10; 20toQ	17389	17.389	21.3	168.754	14.550	82	66	139.4	12.0	Coil 105, I3-I6
MQXFS3b	05/12/2016	1.9	47	45	200	50to10; 20toQ	17319	17.319	21.3	168.754	14.550	81	66	138.9	12.0	Coil 105, I3-I6
MQXFS3b	05/12/2016	1.9	48	46	200	50to10; 20toQ	17471	17.471	21.3	168.754	14.550	82	67	140.0	12.1	Coil 106, O3-O2
MQXFS3b	05/12/2016	1.9	49	47	200	50to10; 20toQ	17543	17.543	21.3	168.754	14.550	82	68	140.6	12.1	Coil 7, I3-I4
MQXFS3b	05/12/2016	1.9	50	48	200	50to10; 20toQ	17601	17.601	21.3	168.754	14.550	83	68	141.0	12.2	Coil 105, I3-I6
MQXFS3b	06/12/2016	1.9	51	49	200	50to10; 20toQ	17677	17.677	21.3	168.754	14.550	83	69	141.6	12.2	Coil 105, I7-I8
MQXFS3b	06/12/2016	1.9	52	50	200	200toQ	17591	17.591	21.3	168.754	14.550	82	68	140.9	12.1	Coil 105, I7-I8
MQXFS3b	07/12/2016	1.9	53	51	200	200toQ	17551	17.551	21.3	168.754	14.550	82	68	140.6	12.1	Coil 105, I7-I8
MQXFS3b	07/12/2016	1.9	54	52	100	100toQ	17519	17.519	21.3	168.754	14.550	82	67	140.4	12.1	Coil 105, I7-I8
MQXFS3b	09/12/2016	1.9	55	53	20	50to10; 20toQ	16693	16.693	21.3	168.754	14.550	78	61	134.2	11.6	Coil 7, I3-I4
MQXFS3b	09/12/2016	1.9	56	54	20	50to10; 20toQ	16724	16.724	21.3	168.754	14.550	78	61	134.5	11.6	Coil 7, I3-I4
MQXFS3b	09/12/2016	1.9	57	55	200	200toQ	17445	17.445	21.3	168.754	14.550	82	67	139.8	12.1	Coil 105, I8-O1
MQXFS3b	09/12/2016	1.9	58	56	200	200toQ	17637	17.637	21.3	168.754	14.550	83	68	141.3	12.2	Coil 107, I8-O1
MQXFS3b	09/12/2016	1.9	59	57	200	200toQ	17737	17.737	21.3	168.754	14.550	83	69	142.0	12.2	Coil 105, I7-I8
MQXFS3b	09/12/2016	1.9	60	58	200	200toQ	17553	17.553	21.3	168.754	14.550	82	68	140.6	12.1	Coil 106, O3-O2
MQXFS3b	09/12/2016	1.9	61	59	200	200toQ	17748	17.748	21.3	168.754	14.550	83	69	142.1	12.2	Coil 7, I4-I6
MQXFS3b	12/12/2016	4.3	62	60	20	50to10; 20toQ	17676	17.676	19.4	154.4	13.3	91	83	141.5589	12.20182	Coil 105, I8-O1
MQXFS3b	12/12/2016	4.3	63	61	20	50to10; 20toQ	17542	17.542	19.4	154.4	13.3	90	82	140.5613	12.11511	Coil 105, I8-O1

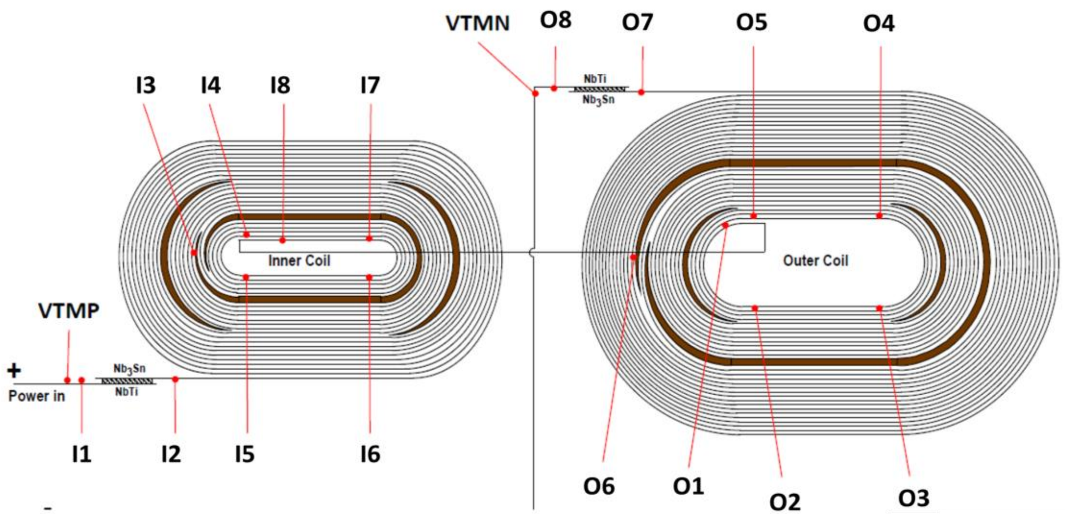
MQXFS3c

MQXFS3c	08/12/2017	1.9	64	62	20	50to10; 20toQ	15551	15.551	21.3	168.754	14.550	73	53	125.7144	10.82506	Coil 106, O4-O7
MQXFS3c	11/12/2017	1.9	65	63	20	50to10; 20toQ	15134	15.134	21.3	168.754	14.550	71	50	122.5943	10.55411	Coil 106, O4-O7
MQXFS3c	11/12/2017	1.9	66	64	20	50to10; 20toQ	15614	15.614	21.3	168.754	14.550	73	54	126.1854	10.86597	Coil 106, O4-O7
MQXFS3c	11/12/2017	1.9	67	65	20	50to10; 20toQ	15230	15.23	21.3	168.754	14.550	71	51	123.3131	10.61652	Coil 106, O4-O7
MQXFS3c	12/12/2017	1.9	68	66	20	50to10; 20toQ	15340	15.34	21.3	168.754	14.550	72	52	124.1363	10.68801	Coil 106, O4-O7
MQXFS3c	12/12/2017	1.9	69	67	20	50to10; 20toQ	15523	15.523	21.3	168.754	14.550	73	53	125.5051	10.80688	Coil 106, O4-O7
MQXFS3c	12/12/2017	1.9	70	68	20	50to10; 20toQ	15617	15.617	21.3	168.754	14.550	73	54	126.2078	10.86792	Coil 106, O4-O7
MQXFS3c	12/12/2017	1.9	71	69	20	50to10; 20toQ	15520	15.52	21.3	168.754	14.550	73	53	125.4827	10.80493	Coil 106, O4-O7
MQXFS3c	13/12/2017	1.9	72	70	200	200toQ	16878	16.878	21.3	168.754	14.550	79	63	135.6162	11.68533	Coil 106, O4-O7
MQXFS3c	13/12/2017	1.9	73	71	200	200toQ	17156	17.156	21.3	168.754	14.550	80	65	137.6871	11.8653	Coil 106, O4-O7
MQXFS3c	13/12/2017	1.9	74	72	200	200toQ	17225	17.225	21.3	168.754	14.550	81	65	138.2009	11.90996	Coil 106, O4-O7
MQXFS3c	13/12/2017	1.9	75	73	200	200toQ	16545	16.545	21.3	168.754	14.550	78	60	133.1345	11.46967	Coil 8, O5-O6
MQXFS3c	13/12/2017	1.9	76	74	200	200toQ	17245	17.245	21.3	168.754	14.550	81	65	138.3499	11.92291	Coil 105, I3-I6
MQXFS3c	14/12/2017	1.9	77	75	200	200toQ	17528	17.528	21.3	168.754	14.550	82	68	140.457	12.10605	Coil 8, I5-I6
MQXFS3c	14/12/2017	1.9	78	76	200	200toQ	17682	17.682	21.3	168.754	14.550	83	69	141.6035	12.20571	Coil 105, I3-I6
MQXFS3c	14/12/2017	1.9	79	77	20	20	15622	15.622	21.3	168.754	14.550	73	54	126.2452	10.87116	Coil 106, O4-O7
MQXFS3c	14/12/2017	1.9	80	78	200	200toQ	18032	18.032	21.3	168.754	14.550	85	71	144.209	12.43218	Coil 105, I3-I6
MQXFS3c	15/12/2017	1.9	81	79	200	200toQ	18094	18.094	21.3	168.754	14.550	85	72	144.6705	12.47229	C107, O2O3
MQXFS3c	15/12/2017	1.9	82	80	200	200toQ	18094	18.094	21.3	168.754	14.550	85	72	144.6705	12.47229	Coil 8, I3I4
MQXFS3c	15/12/2017	1.9	83	81	200	200toQ	18091	18.091	21.3	168.754	14.550	85	72	144.6482	12.47035	C107, O2O3
MQXFS3c	18/12/2017	1.9	84	82	200	200toQ	18098	18.098	21.3	168.754	14.550	85	72	144.7003	12.47488	C107, O2O3
MQXFS3c	18/12/2017	1.9	85	83	100	200toQ	18220	18.22	21.3	168.754	14.550	85	73	145.6085	12.55383	Coil 106, O4-O7
MQXFS3c	18/12/2017	4.2	86	84	20	200toQ	17522	17.522	19.4	154.4	13.3	90	82	140.4124	12.10217	C107, O2O3
MQXFS3c	18/12/2017	4.2	87	85	20	200toQ	17368	17.368	19.4	154.4	13.3	90	80	139.2658	12.00251	C107, O2O3
MQXFS3c	26/01/2018	1.9	86	86	20	50to10; 20toQ	15220	15.22	21.3	168.754	14.550	71	51	123.2382	10.61002	Coil 106, O4O7
MQXFS3c	26/01/2018	1.9	87	87	20	50to10; 20toQ	15422	15.422	21.3	168.754	14.550	72	52	124.7498	10.74128	Coil 106, O4O7
MQXFS3c	26/01/2018	1.9	88	88	200	200toQ	17672	17.672	21.3	168.754	14.550	83	69	141.5291	12.19923	Coil 106, O4O7
MQXFS3c	26/01/2018	1.9	89	89	200	200toQ	17889	17.889	21.3	168.754	14.550	84	70	143.1445	12.33965	Coil 105, I3I6
MQXFS3c	29/01/2018	1.9	90	90	200	200toQ	17966	17.966	21.3	168.754	14.550	84	71	143.7177	12.38947	Coil 107, O2O3
MQXFS3c	30/01/2018	1.9	91	91	200	200toQ	17966	17.966	21.3	168.754	14.550	84	71	143.7177	12.38947	Coil 107, O2O3
MQXFS3c	30/01/2018	1.9	92	92	200	200toQ	17986	17.986	21.3	168.754	14.550	84	71	143.8666	12.40241	Coil 107, O2O3
MQXFS3c	02/02/2018	1.9	93	93	200	fter holding at 13.5 k	17954	17.954	21.3	168.754	14.550	84	71	143.6283	12.38171	Coil 106, I4I2
MQXFS3c	02/06/2018	1.9	94	94	150	150toQ	18204	18.204	21.3	168.754	14.550	85	73	145.4894	12.54347	Coil 105, I3I6
MQXFS3c	02/09/2018	1.9	95	95	150	150toQ	18198	18.198	21.3	168.754	14.550	85	73	145.4447	12.53959	Coil 107, O2O3
MQXFS3c	20/02/2018	1.9	95	95	50	50toQ	15894	15.894	21.3	168.754	14.550	75	56	128.2773	11.04768	Coil 106, O4O7
MQXFS3c	20/02/2018	1.9	96	96	20	20toQ	15296	15.296	21.3	168.754	14.550	72	51	123.8071	10.65942	Coil 106, O4O7
MQXFS3c	21/02/2018	1.9	97	97	150	150toQ	18205	18.205	21.3	168.754	14.550	85	73	145.4968	12.54412	Coil 107, I2I3
MQXFS3c	22/02/2018	4.5	98	98	20	20toQ	17248	17.248	19.4	154.4	13.3	89	79	138.3722	11.92485	Coil 107, O2O3
MQXFS3c	23/02/2018	4.5	99	99	20	20toQ	17568	17.568	19.4	154.4	13.3	91	82	140.7548	12.13194	Coil 107, O2O3
MQXFS3c	26/02/2018	4.5	100	100	20	20toQ	17258	17.258	19.4	154.4	13.3	89	79	138.4467	11.93132	Coil 107, O2O3
MQXFS3c	27/02/2018	1.9	101	101	20	20toQ	15380	15.38	21.3	168.754	14.550	72	52	124.4356	10.714	Coil 106, O4O7
MQXFS3c	28/02/2018	1.9	102	102	20	20toQ	15506	15.506	21.3	168.754	14.550	73	53	125.378	10.79584	Coil 106, O4O7
MQXFS3c	28/02/2018	1.9	103	103	20	20toQ	15272	15.272	21.3	168.754	14.550	72	51	123.6275	10.64382	Coil 106, O4O7
MQXFS3c	28/02/2018	1.9	104	104	20	20toQ	15180	15.18	21.3	168.754	14.550	71	51	122.9388	10.58402	Coil 106, O4O7
MQXFS3c	03/03/2018	4.5	105	105	20	20toQ	17256	17.256	19.4	154.4	13.3	89	79	138.4318	11.93003	Coil 107, O2O3

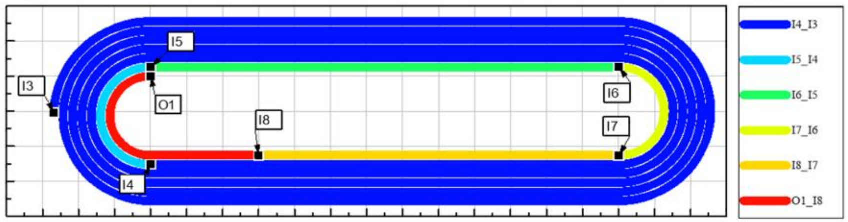
MQXFS3



I2
I1
I5
I6
I3
Inner layer
I4
I7
I8
O7
O4
O8
O5
O1
O6
Outer layer
O2
O3



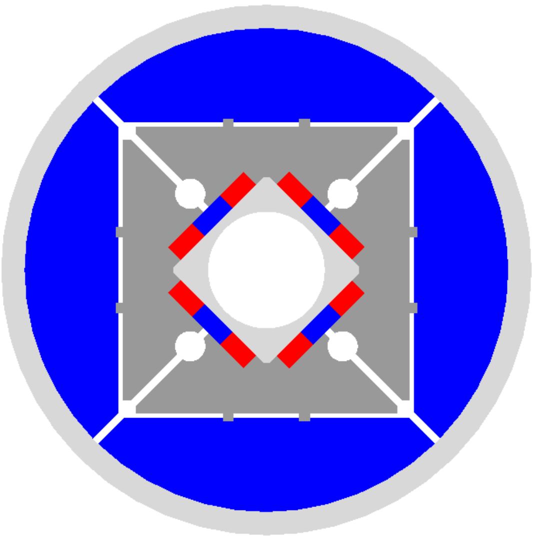
VTMN
O8
O7
O5
O4
I3
I4
I8
I7
NbTi
Nb3Sn
Inner Coil
Outer Coil
VTMP
+
Power in
Nb3Sn
NbTi
I1
I2
I5
I6
O6
O1
O2
O3
-

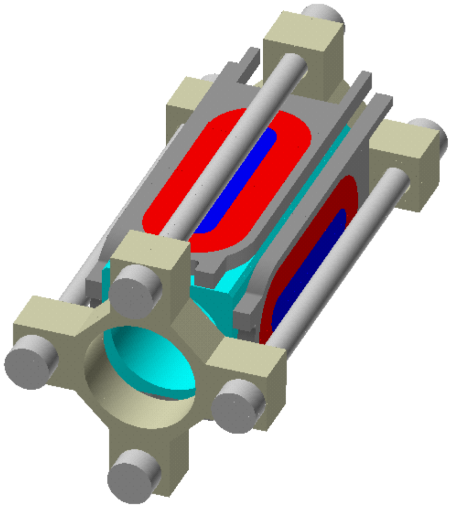


I5
I3
O1
I8
I6
I7
I4
I4_I3
I5_I4
I6_I5
I7_I6
I8_I7
O1_I8

Magnet design
Support structure

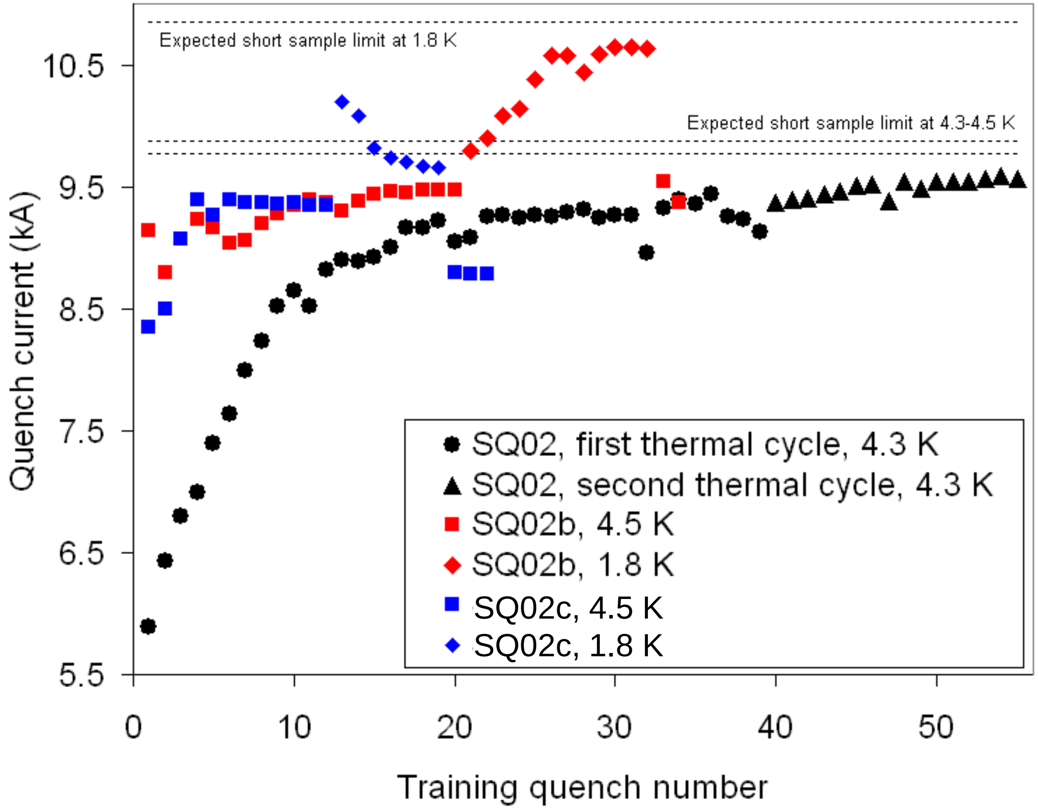
- Stainless steel pads
- Iron yokes
- Aluminum shell
  - Thickness: 22 mm
  - Outer diameter: 500 mm
- 4 bladders and 8 keys for assembly and pre-load
- Axial support
  - 4 aluminum rods
    - Diameter: 25 mm
  - Stainless steel end plate
    - Thickness: 50 mm
  - Pre-load applied with hydraulic cylinder
- Strain gauges on shell and rods





SQ02c
Quench performance

- 1^{st} quench at 4.5 K
  - 8.3 kA (85% I_{ss})
- Highest quench at 4.5 K
  - 9.4 kA (96% I_{ss})
  - Coil 18, RE
- 1^{st} quench at 1.8 K
  - 10.2 kA (94% I_{ss})
- Last quench at 1.8 K
  - 9.7 kA (89% I_{ss})
  - Coil 17, LE
- Last quench at 4.5 K
  - 8.8 kA (90% I_{ss})
  - Coil 17 LE



Outline

- Introduction
- Assembly and loading
- Test results

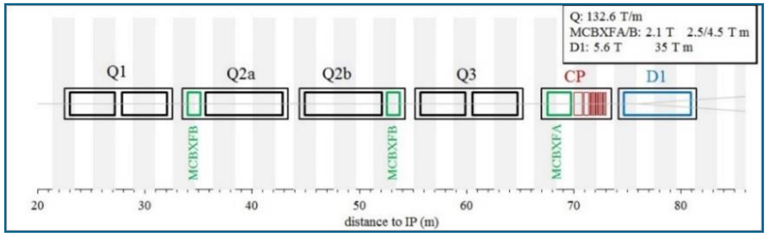
Introduction
HiLumi low-β quadrupole MQXF

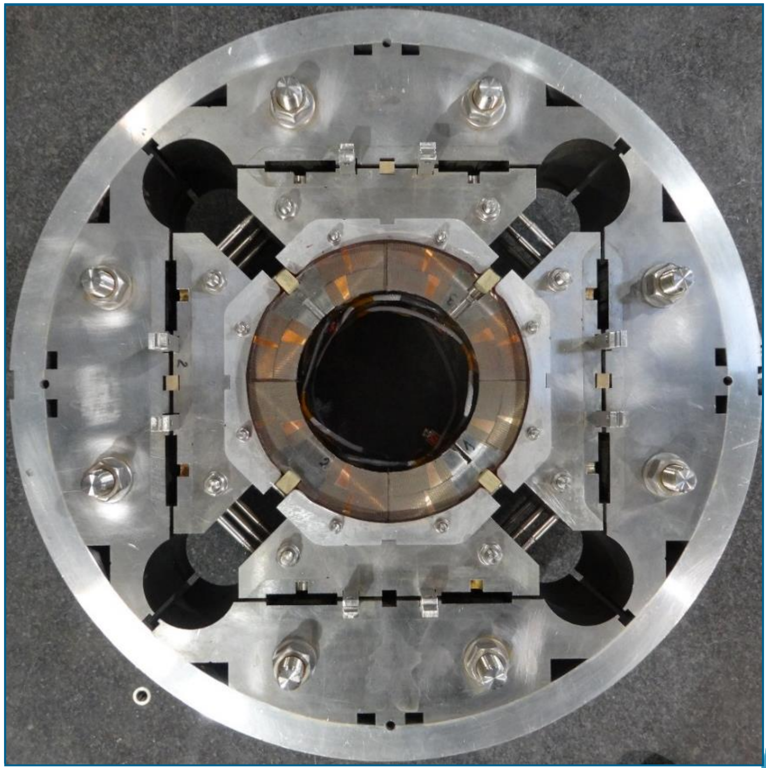
- Target: 132.6 T/m
  - 150 mm aperture, 11.4 T B_{peak}

- Q1/Q3 (by AUP)
  - 2 magnets MQXFA with 4.2 m
    - Series: 20 magnets

- Q2a/Q2b (by CERN)
  - 1 magnet MQXFB with 7.15 m
    - Series: 10 magnets

- Different lengths, same design
  - Identical short models





Introduction

- Tests
  - **2 single-coil tests**
    - MQXFSM1 (1.2 m)
    - MQXFAM1 (4.0 m)
  - **4 short models (1.2 m)**
    - MQXFS1
    - MQXFS3
    - MQXFS5
    - MQXFS4
  - **2 MQXFA prototypes**
    - MQXFAP1 (4.0 m)
    - MQXFAP2 (4.2 m)
- Assembly **MQXFB prototype** (7.15 m) in progress
- Total of 31 coils "used"

PARAMETERS OF COIL USED IN SHORT MODELS AND PROTOTYPES

Coil	Laboratory[a]	Strand	Cross-section	L_c^b (m)	Magnet
2	LARP/AUP	RRP 108/127	1st gen.	1.19	MQXFSM1
103	CERN	RRP 132/169	1st gen.	1.19	MQXFS1a-d
104	CERN	RRP 132/169	1st gen.	1.19	MQXFS1a-d
3	FNAL/BNL	RRP 108/127	1st gen.	1.19	MQXFS1a-d
5	FNAL/BNL	RRP 108/127	1st gen.	1.19	MQXFS1a-d
105	CERN	RRP 132/169	2nd gen.	1.19	MQXFS3a-c
106	CERN	RRP 132/169	2nd gen.	1.19	MQXFS3a-c
107	CERN	RRP 132/169	2nd gen.	1.19	MQXFS3a-c
7	FNAL	RRP 108/127	2nd gen.	1.19	MQXFS3a-b
8	FNAL/BNL	RRP 144/169	2nd gen.	1.19	MQXFS3c
203	CERN	PIT 192	2nd gen.	1.19	MQXFS5
204	CERN	PIT 192	2nd gen.	1.19	MQXFS5
205	CERN	PIT 192	2nd gen.	1.19	MQXFS5
206	CERN	PIT 192	2nd gen.	1.19	MQXFS5
108	CERN	RRP 108/127	2nd gen.	1.19	MQXFS4
109	CERN	RRP 108/127	2nd gen.	1.19	MQXFS4
110	CERN	RRP 108/127	2nd gen.	1.19	MQXFS4
111	CERN	RRP 108/127	2nd gen.	1.19	MQXFS4
QXFP01	FNAL/BNL	RRP 108/127	1st gen.	4.00	MQXFAM1
QXFP02	FNAL/BNL	RRP 132/169	1st gen.	4.00	MQXFAP1
QXFP03	FNAL	RRP 144/169	2nd gen.	4.00	MQXFAP1
QXFP04	FNAL/BNL	RRP 132/169	2nd gen.	4.00	MQXFAP1
QXFP05	FNAL	RRP 108/127	2nd gen.	4.00	MQXFAP1
QXFA101	FNAL	RRP 108/127	2nd gen.	4.20	MQXFAP2
QXFA102	FNAL/BNL	RRP 108/127	2nd gen.	4.20	MQXFAP2
QXFA104	FNAL	RRP 108/127	2nd gen.	4.20	MQXFAP2
QXFA105	FNAL/BNL	RRP 108/127	2nd gen.	4.20	MQXFAP2
104	CERN	RRP 108/127	2nd gen.	7.15	MQXFBP1
105	CERN	RRP 108/127	2nd gen.	7.15	MQXFBP1
107	CERN	RRP 108/127	2nd gen.	7.15	MQXFBP1
108	CERN	RRP 108/127	2nd gen.	7.15	MQXFBP1

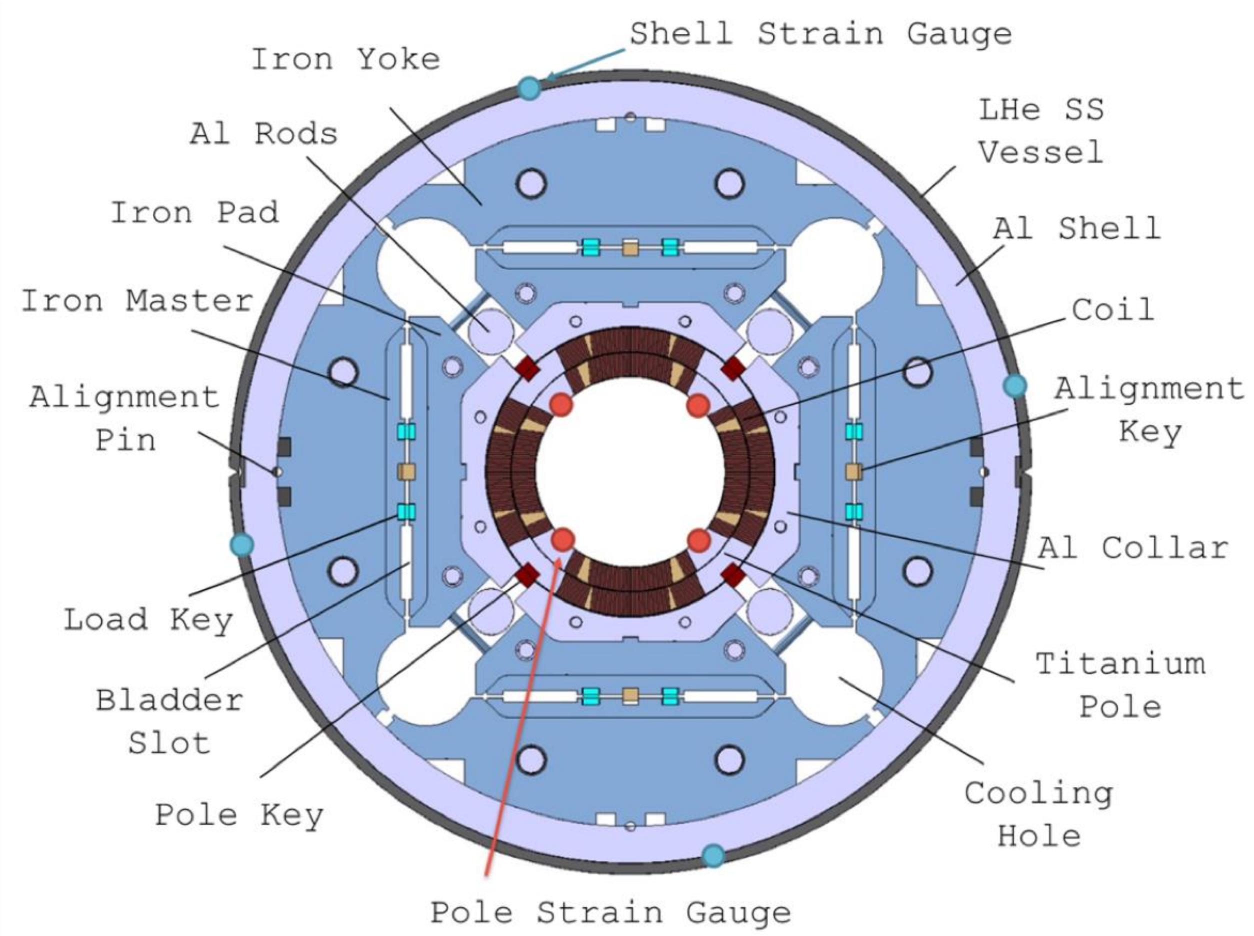
Electrical tests

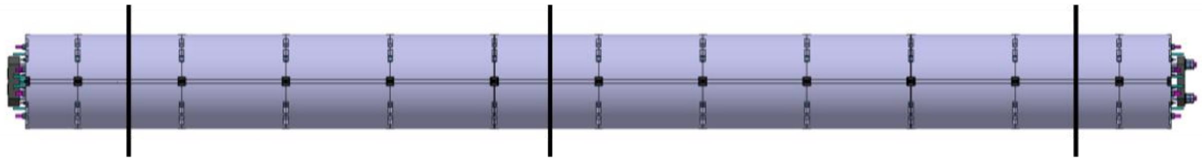
- Coil to QH (requirement)
  - 52 coils, tested in the range 2500-3700 V, all passed
- Coil to floating part (QC)
  - Coil to end-shoe
    - 2 MQXFA coils did not pass (binder issue)
  - Coil to pole
    - Weak insulation (from 20 to 800 MΩ) coil to pole in CERN coils
    - No issue for US coils except 1

Outline

- Introduction
- Assembly and loading
- Test results

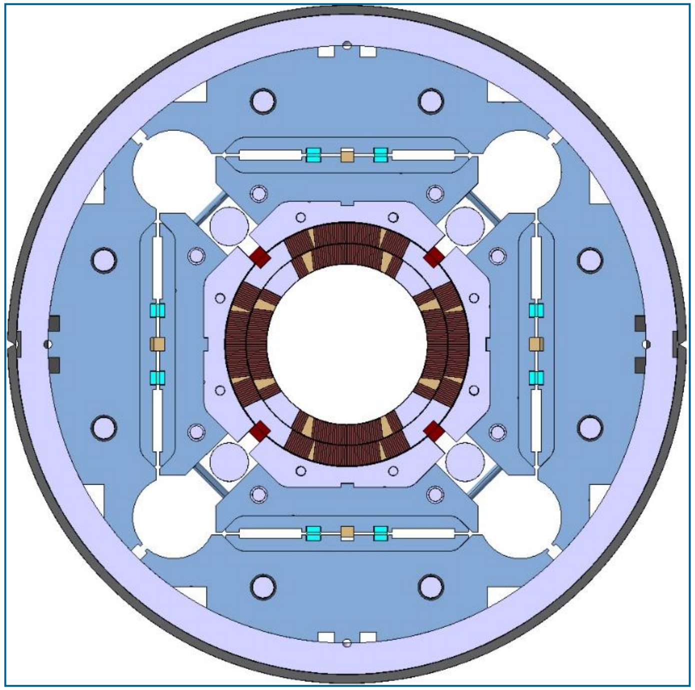
MQXF mechanical structure

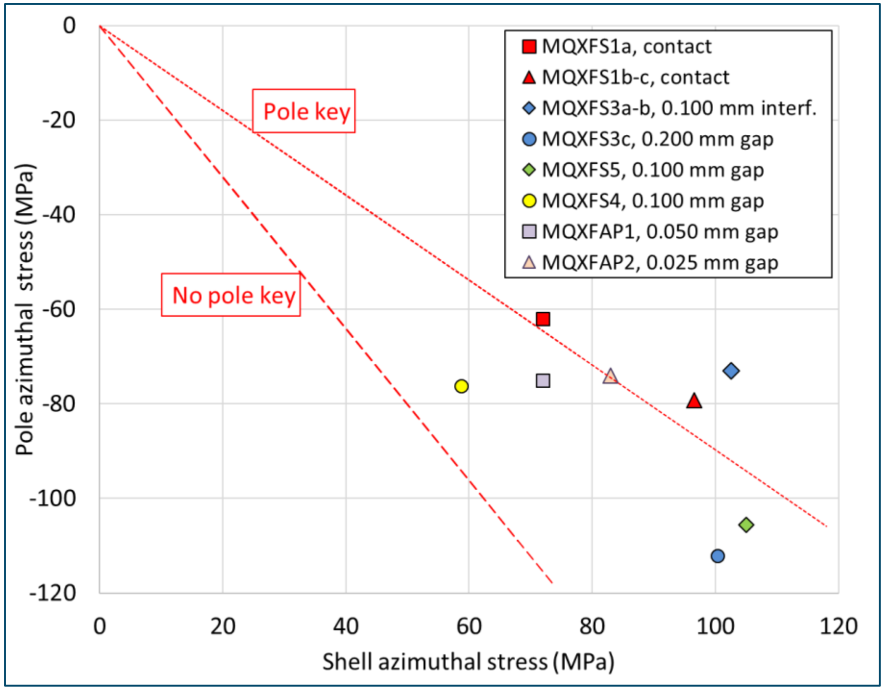




Room temperature pre-load

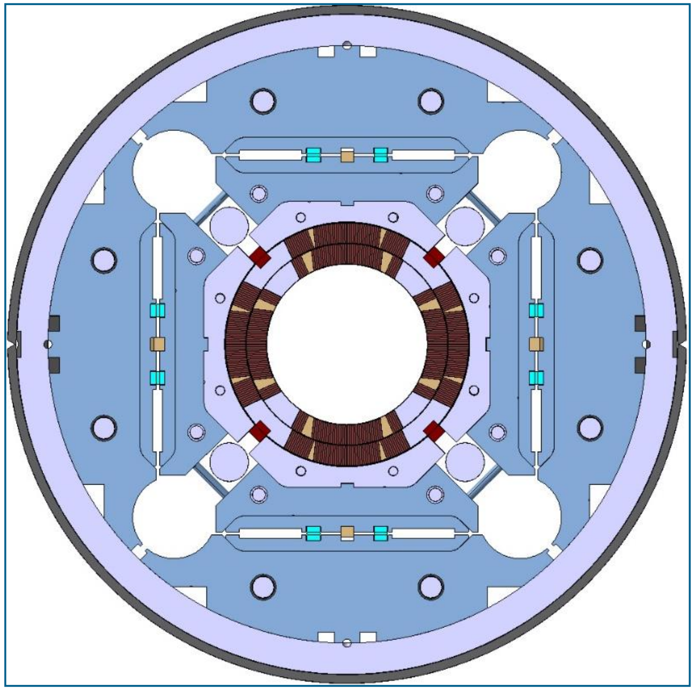
- Pole key – collars
  - from 0.100 interf to 0.200 mm gap.
- Coil pre-load
  - from -60 to -110 MPa

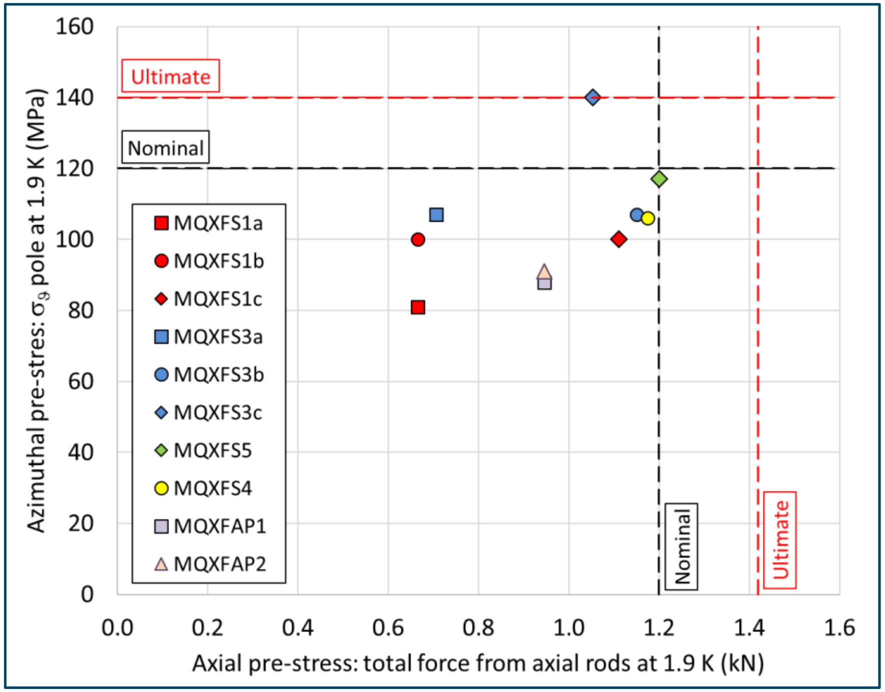




Pre-load after cool-down

- Different level of pre-load achieved
  - Low pre-load in MQXFS1a → unloading before I_{nom}
  - Full pre-load in MQXFS3s → unloading at I_{ult}
- Same approach axially



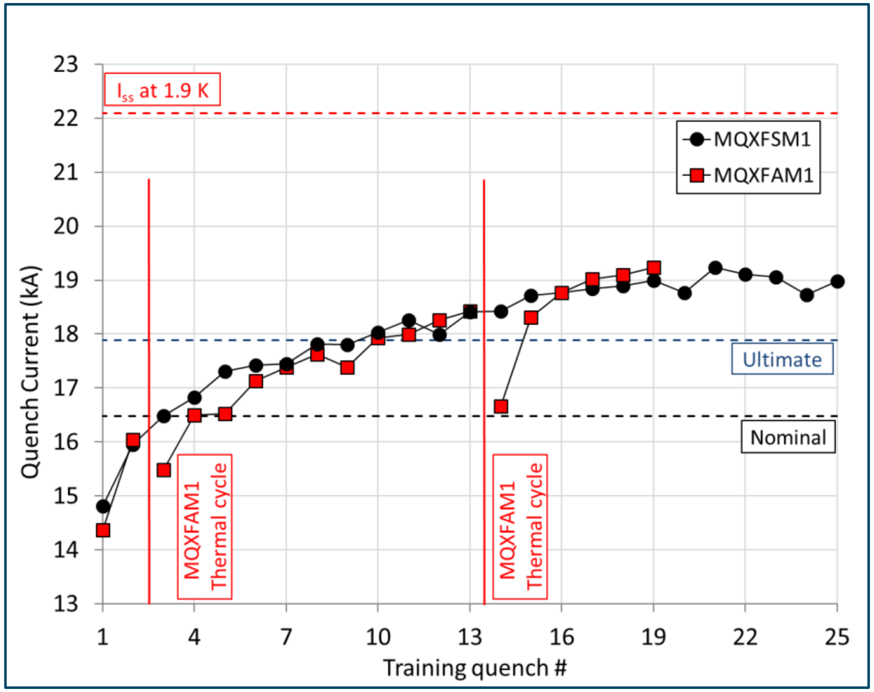


Outline

- Introduction
- Assembly and loading
- Test results

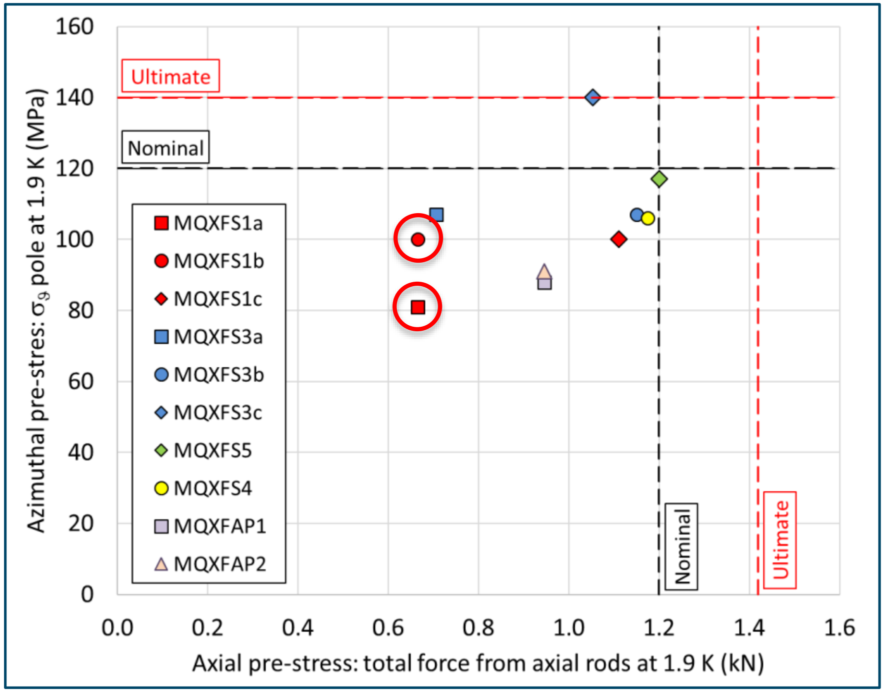
Test results
Single coil tests

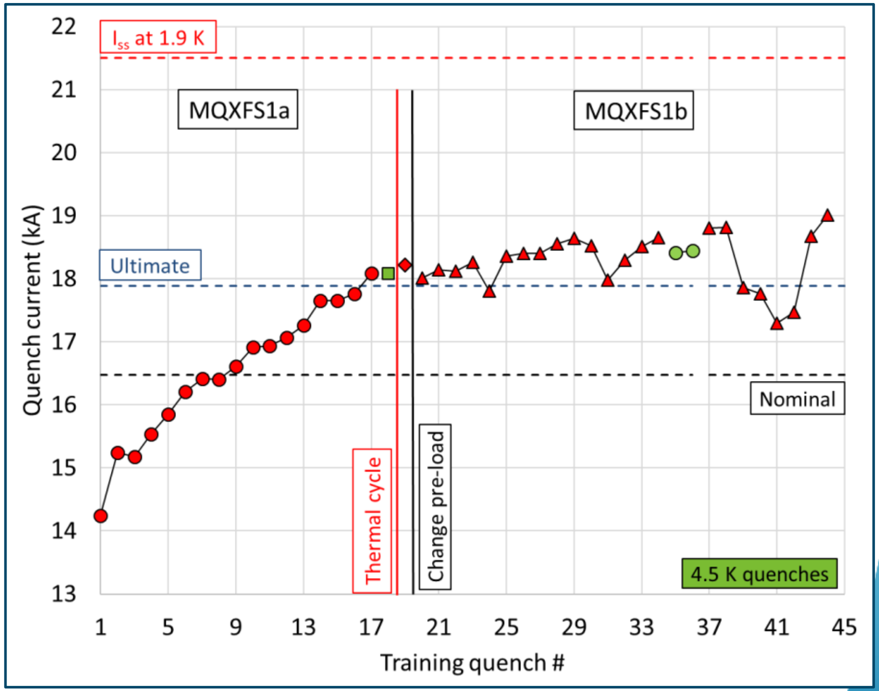
- MQXFSM1, 1.2 m and MQXFAM1, 4.0 m
- Iron structure (“mirror”), load-line similar to MQXFS
- Successful validation of coil design and fabrication procedure → bout 87% of I_{ss}



Test results
MQXFS1

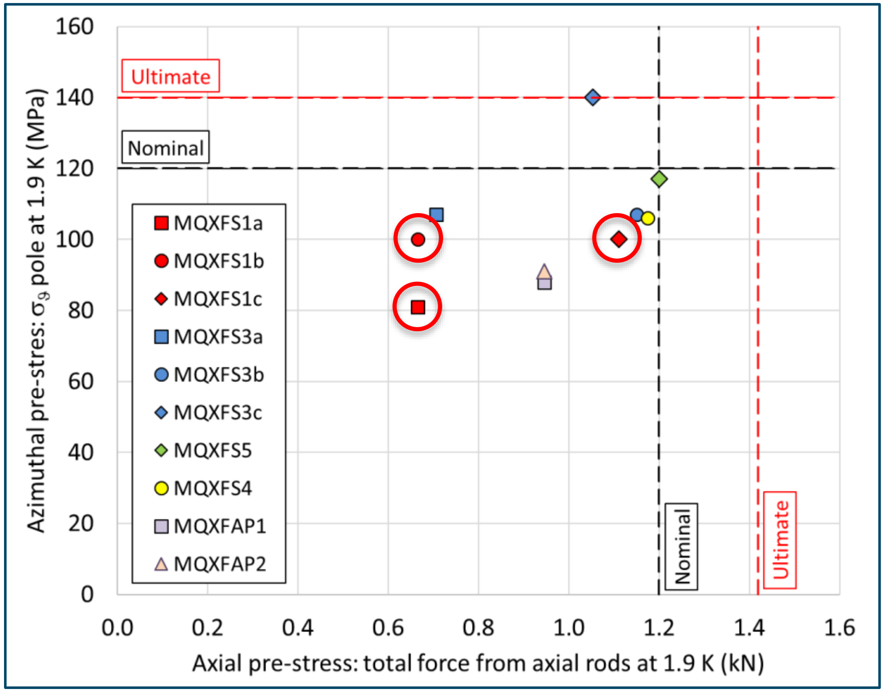
- 1[st] generation coils, RRP 108/127 and 132/169
- MQXFS1a, then increase of azimuthal (MQXFS1b)
  - I_{ult} reached in all tests (some detraining quenches)
  - Up to 19 kA (highest current reached so far)

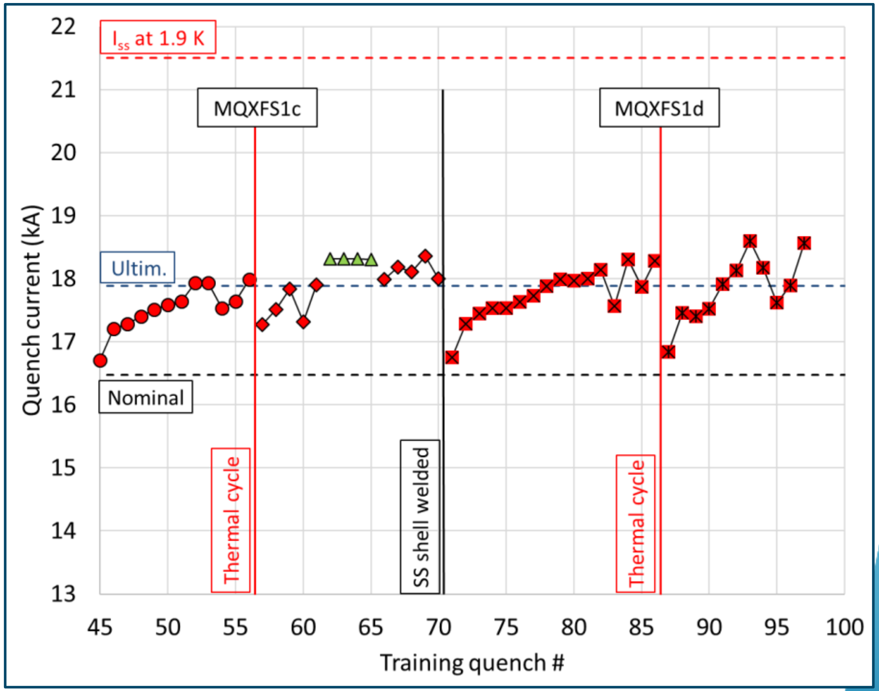




Test results
MQXFS1

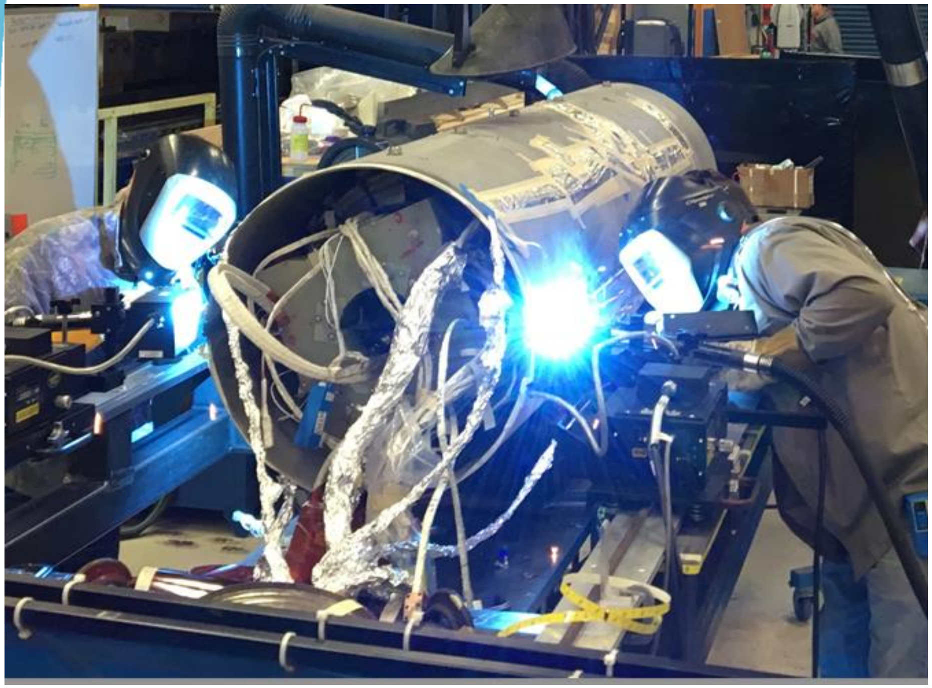
- Then…
  - Increase of axial pre-load (MQXFS1c)
  - I_{ult} reached at 1.9 K and 4.2 K (some detraining and loss of memory)

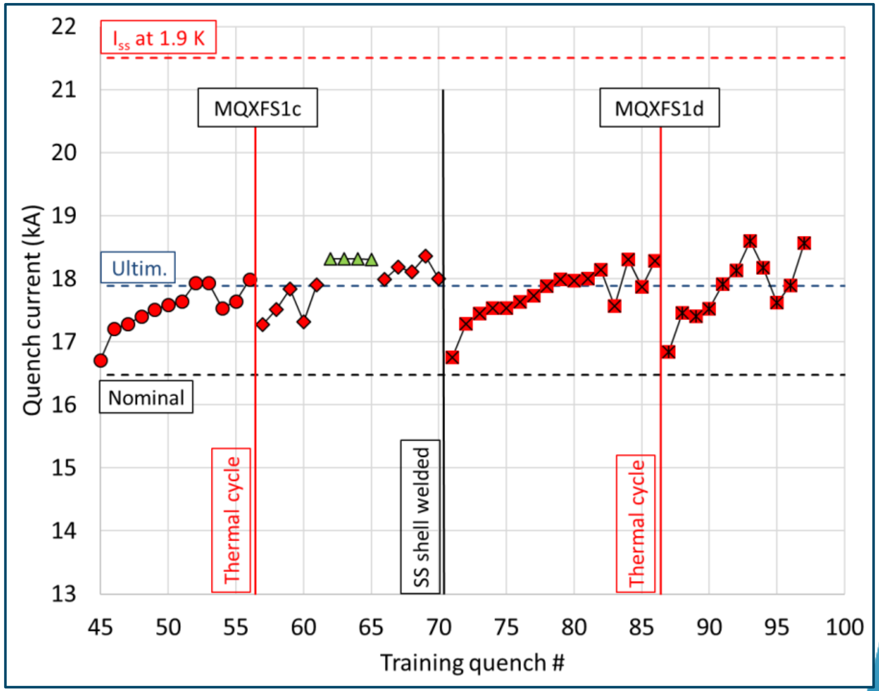




Test results
MQXFS1

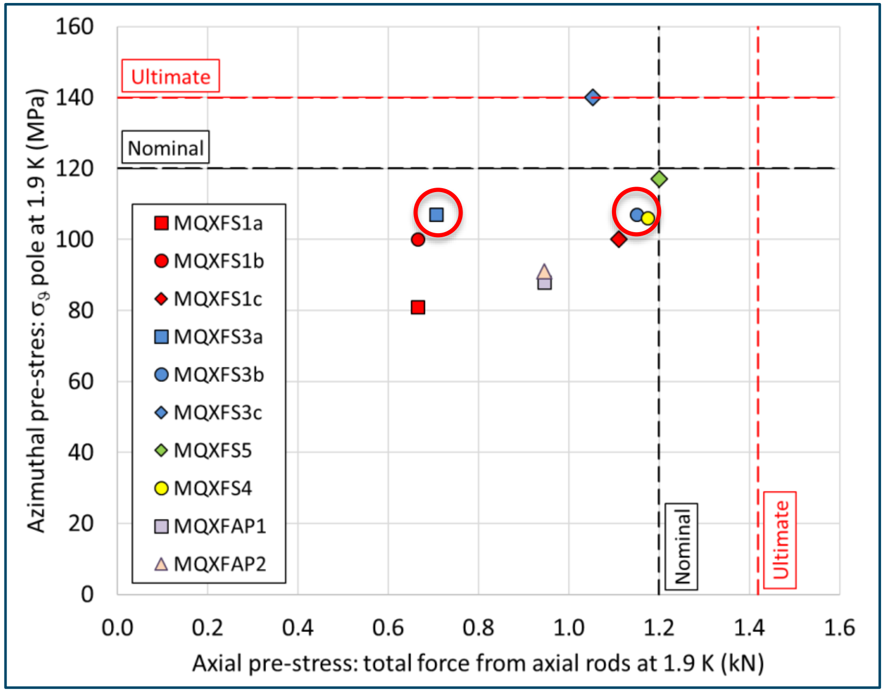
- Then…
  - Stainless steel shell welding (MQXFS1d)
  - Process demonstrated, limited pre-load increase at warm and no pre-load increase at cold

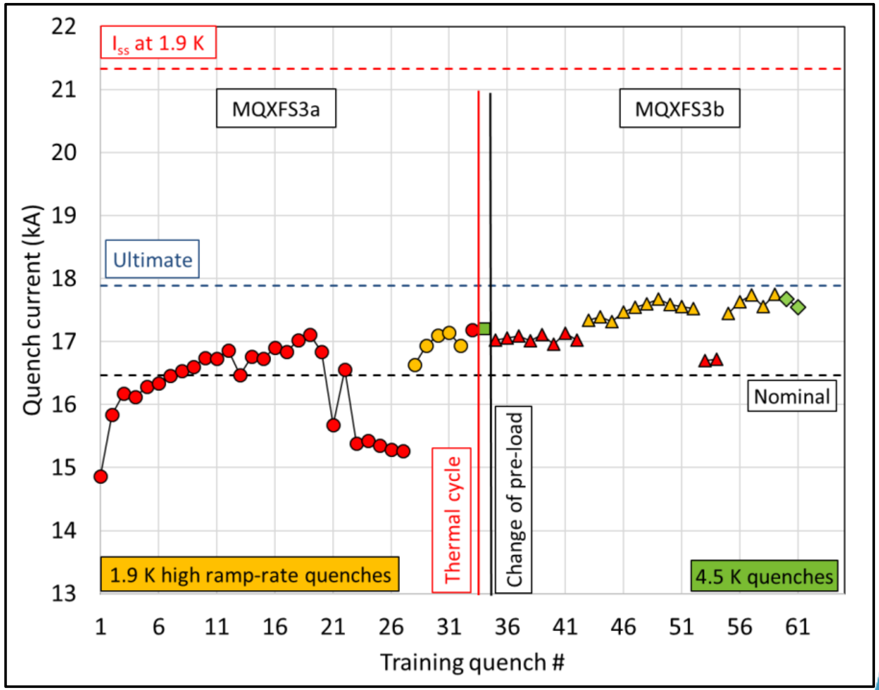




Test results
MQXFS3

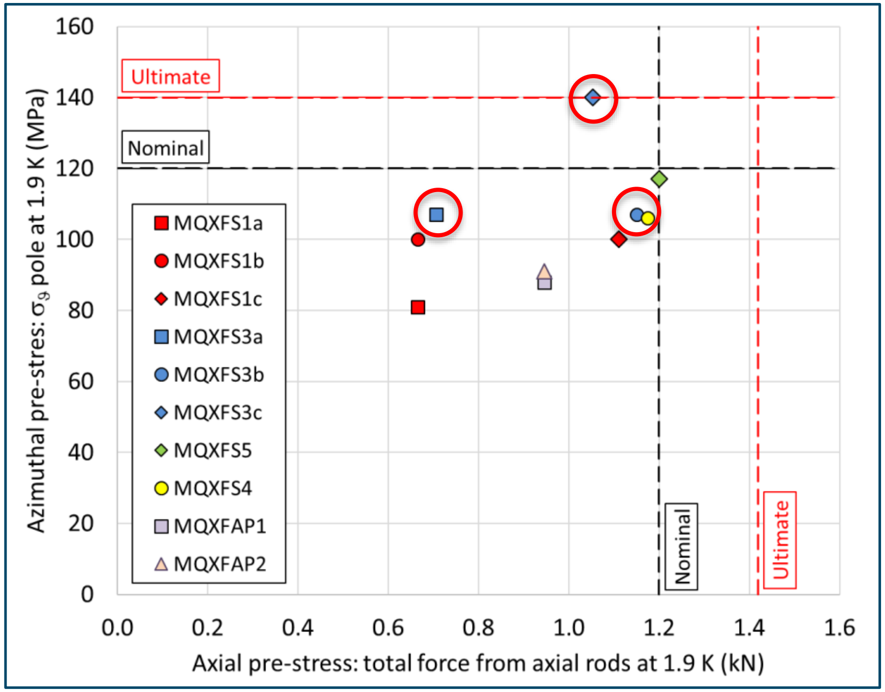
- 2nd generation coils, RRP 108/127, 132/196, 144/169
- MQXFS3a
  - Degradation in end region of coil 7, bypassed at high ramp rates
- Then increase axial (MQXFS3b)
  - Better, but similar behavior

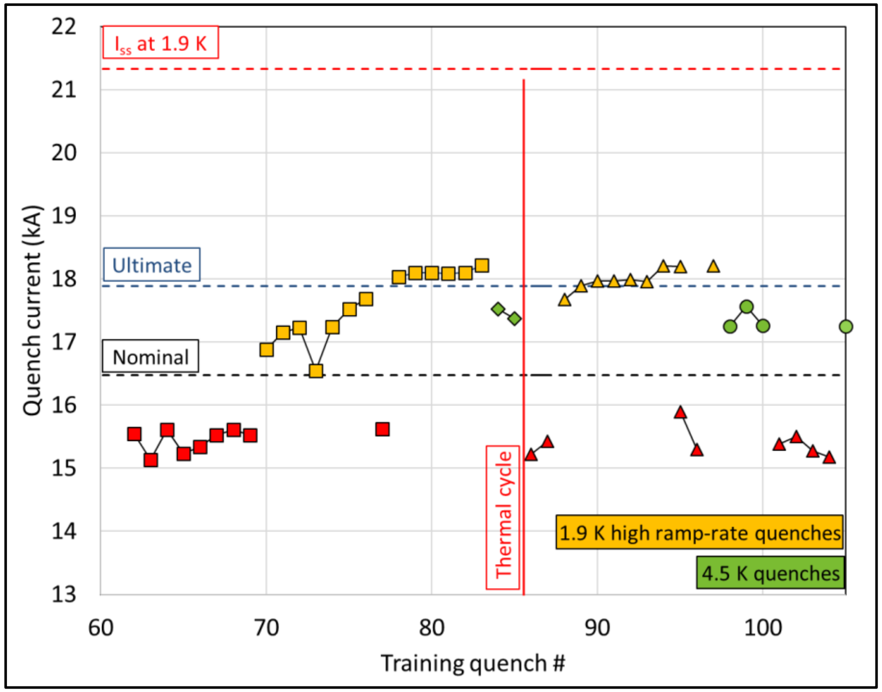




Test results
MQXFS3

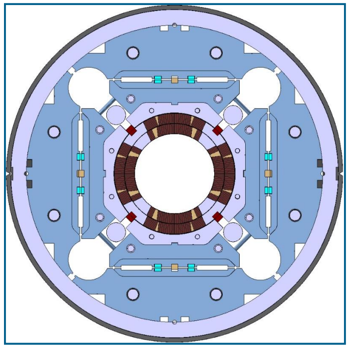
- Then
  - Change of coil and increase azimuthal (MQXFS3c)
  - I_{ult} only at high ramp-rate → limited by "old" coil (106)
    - Interpretation: degradation triggering self-field instability

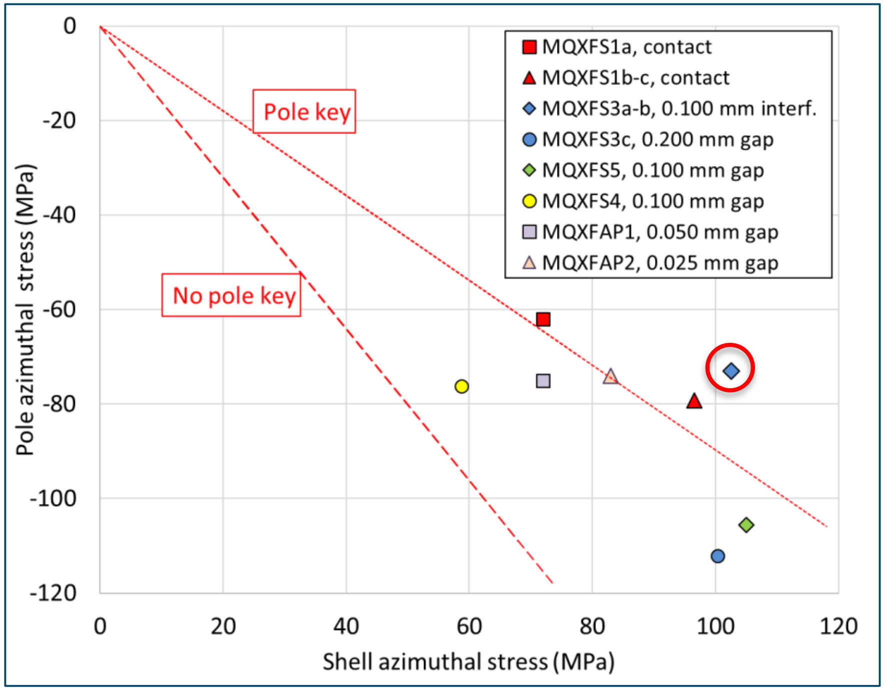


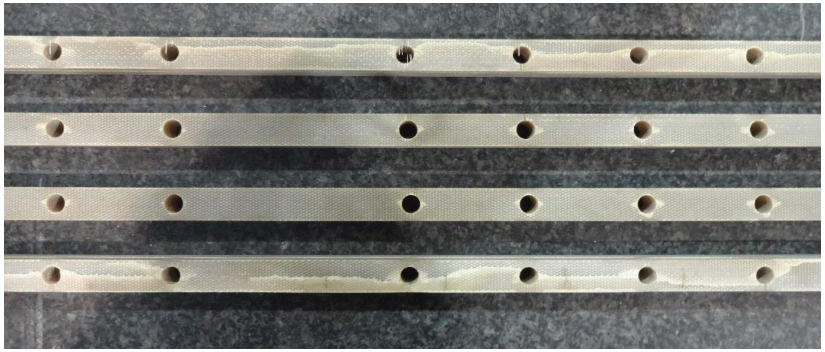


Test results MQXFS3

- MQXFS3a assembled with pole key to collar interference
  - Major damage in pole key

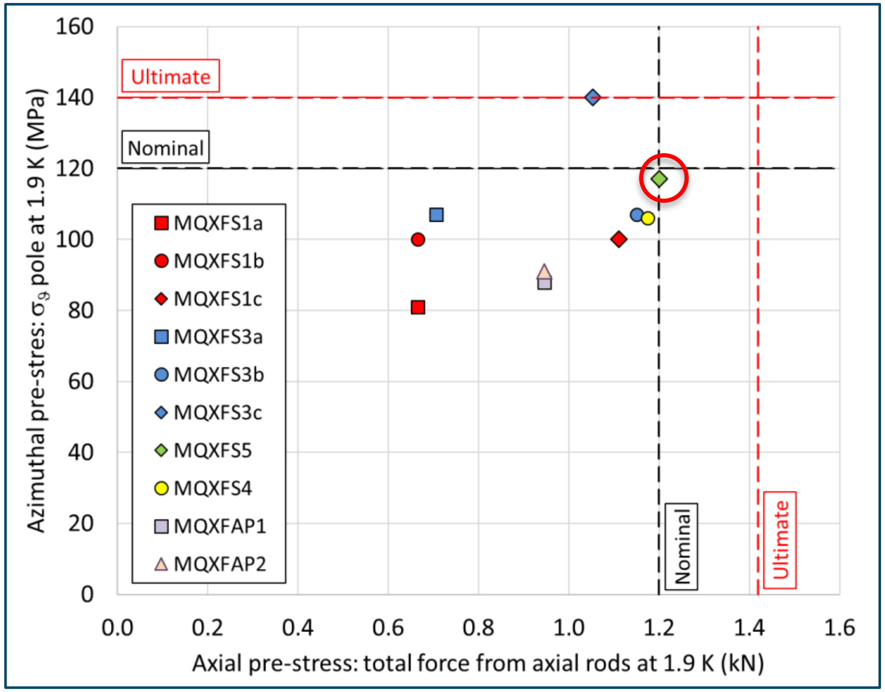


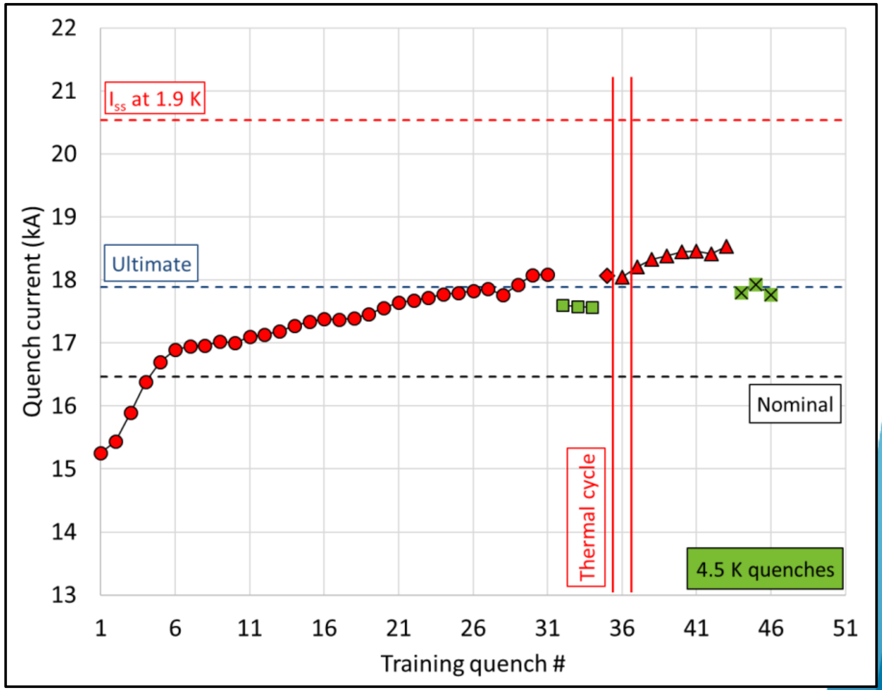




Test results
MQXFS5

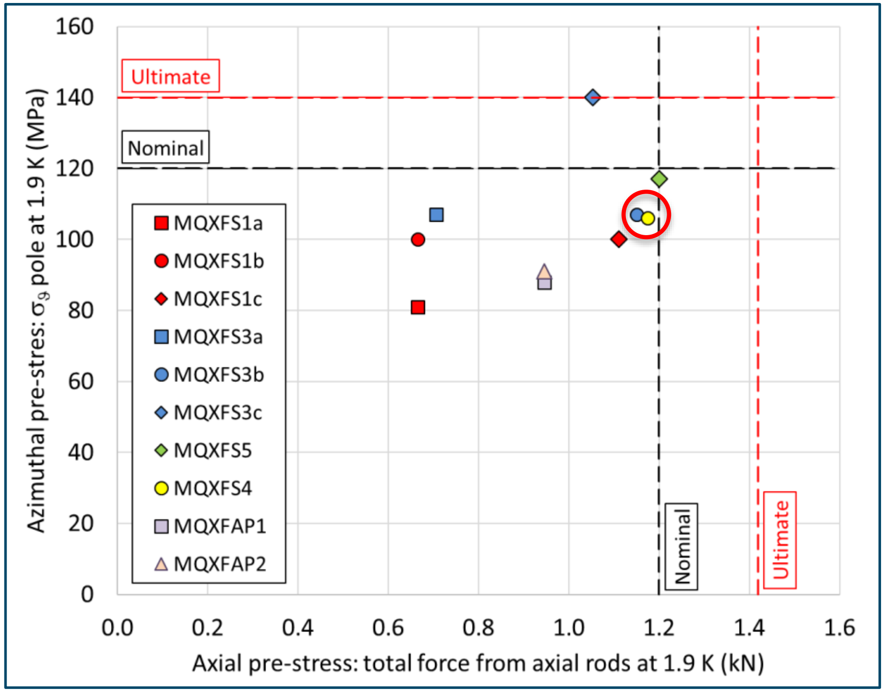
- 2nd generation coils, PIT 192
  - "Nominal" pre-load
  - I_{ult} reached, both at 1.9 K and 4.5 K, with full memory
  - Change of slope during training

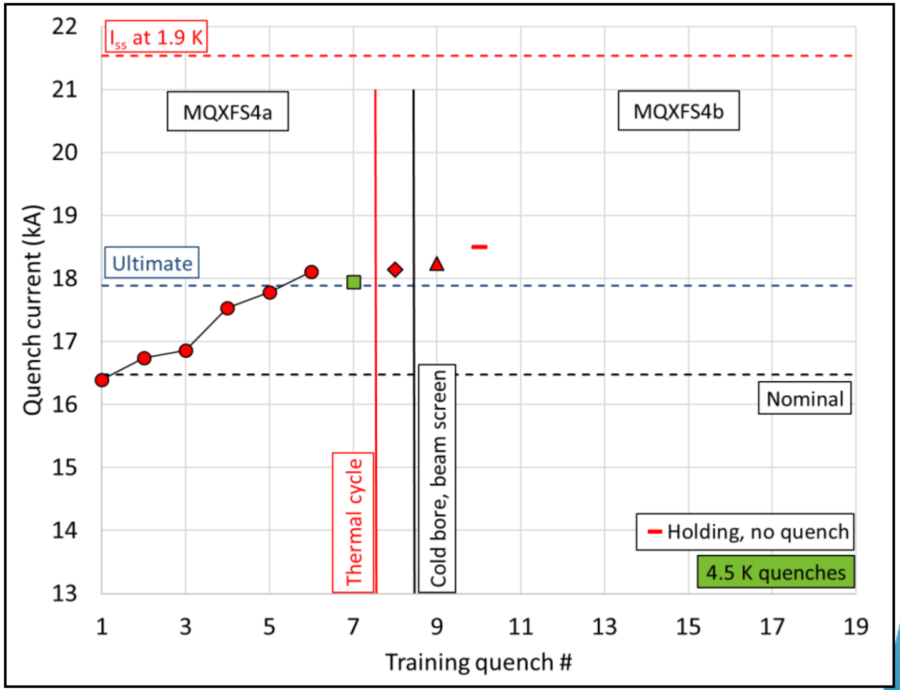




Test results
MQXFS4

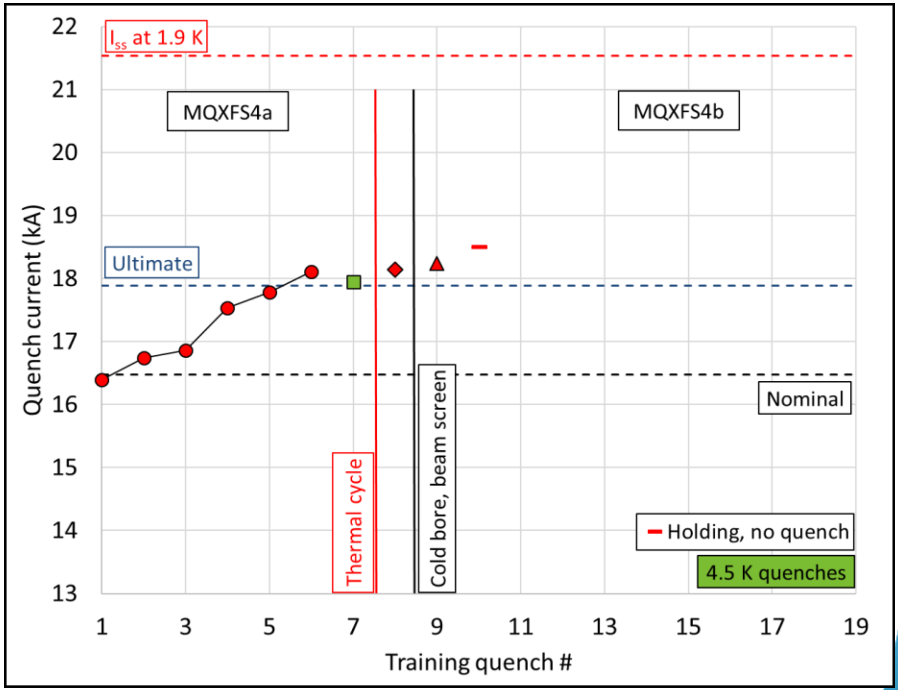
- 2nd generation coils, RRP 108/127
  - "Nominal" pre-load
  - I_{ult} reached, both at 1.9 K and 4.5 K, with full memory
  - Fastest training





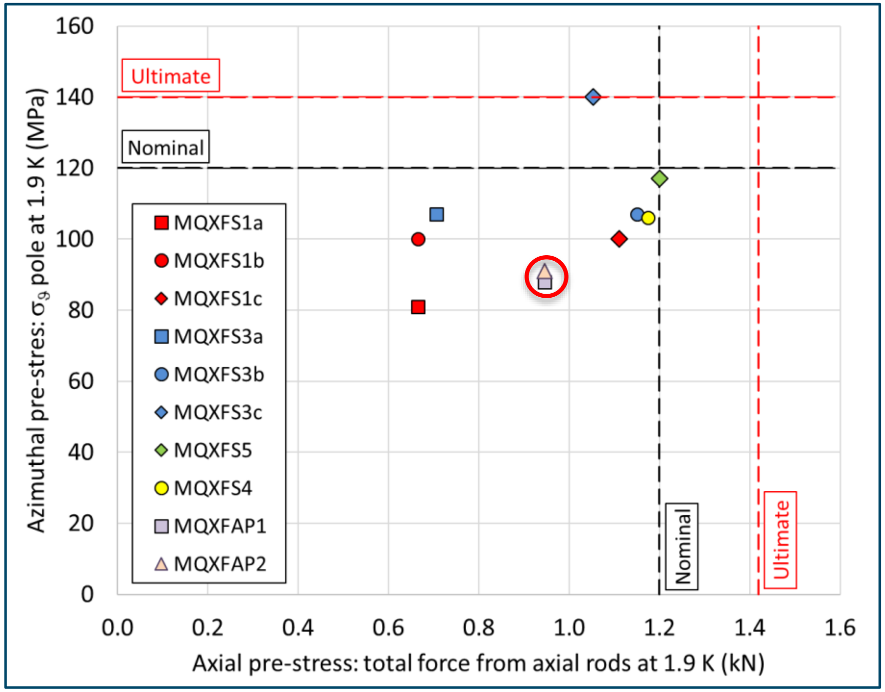
Test results
MQXFS4

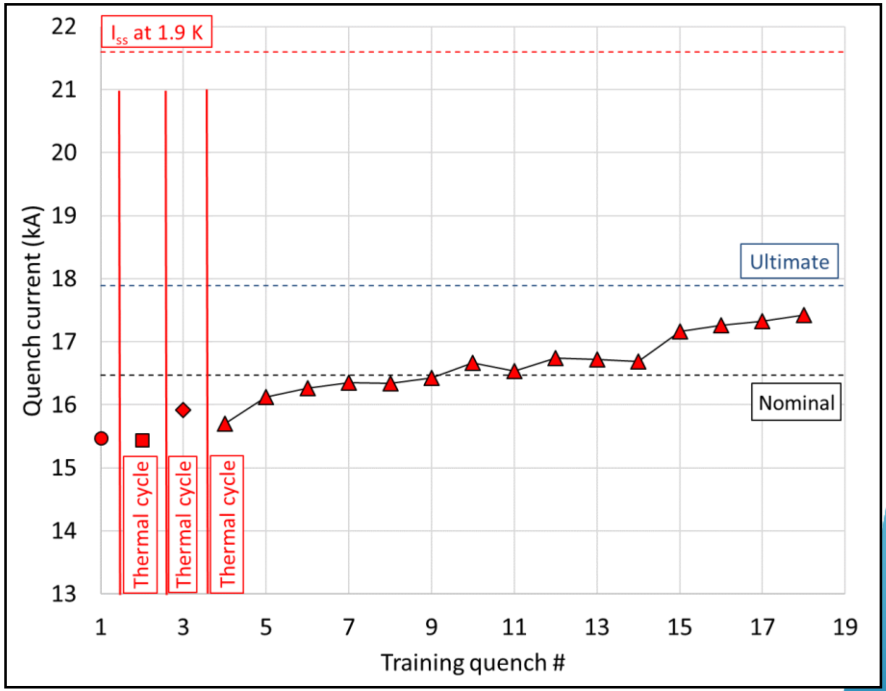
- Then…
  - Insertion of cold bore and beam screen
    - Validation of process
  - No effect on magnet performance



MQXFAP1

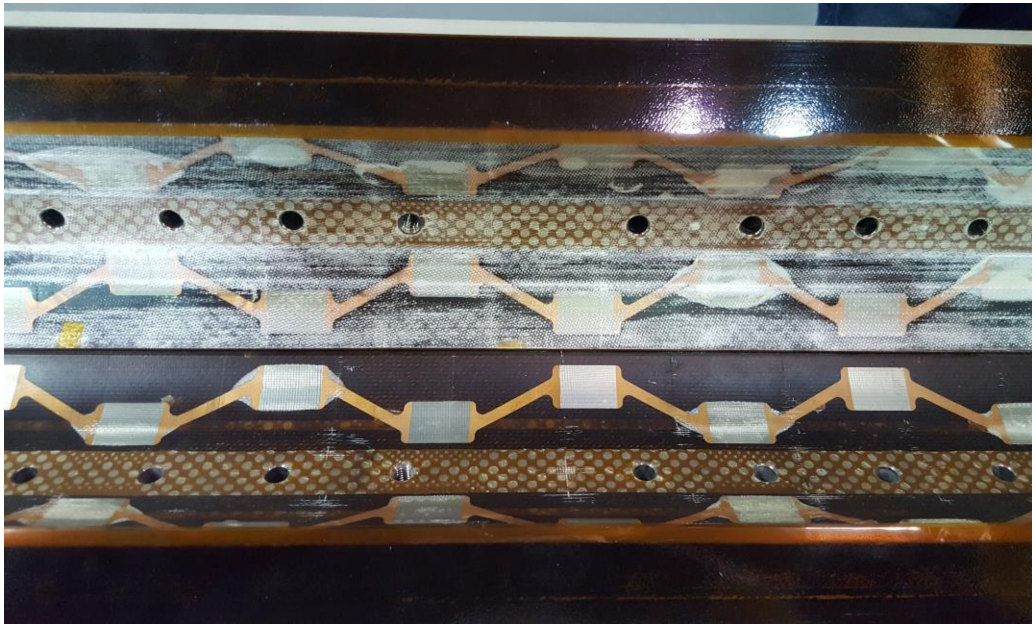
- 1st generation coils, 4.0 m, RRP 108/127, 132/169, 144/169
- 3 thermal cycles for problems in cryogenic system
- I_{nom} reached, training stopped because of a short to ground caused by previous double-short QH to coil





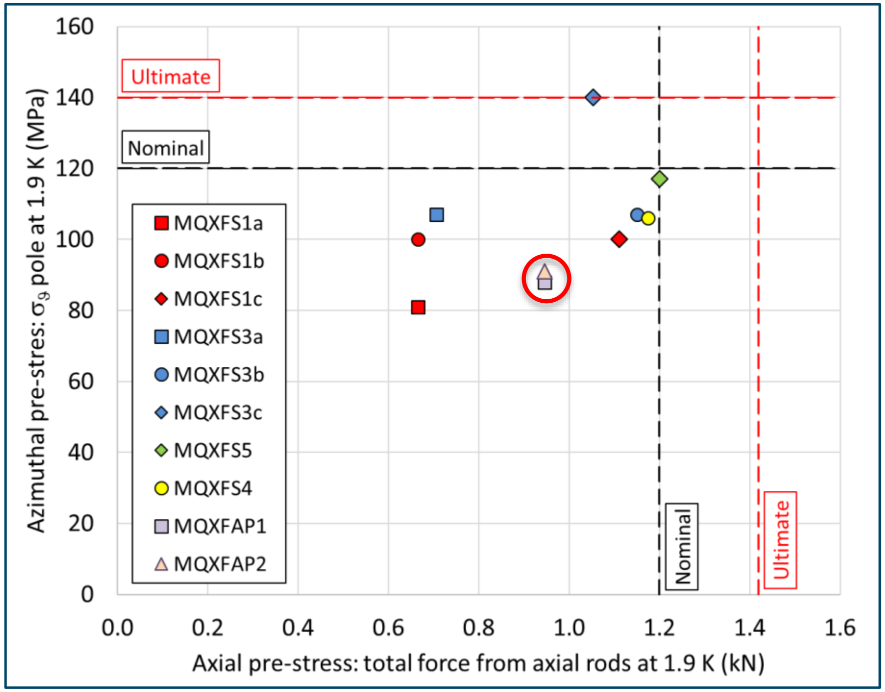
MQXFAP1

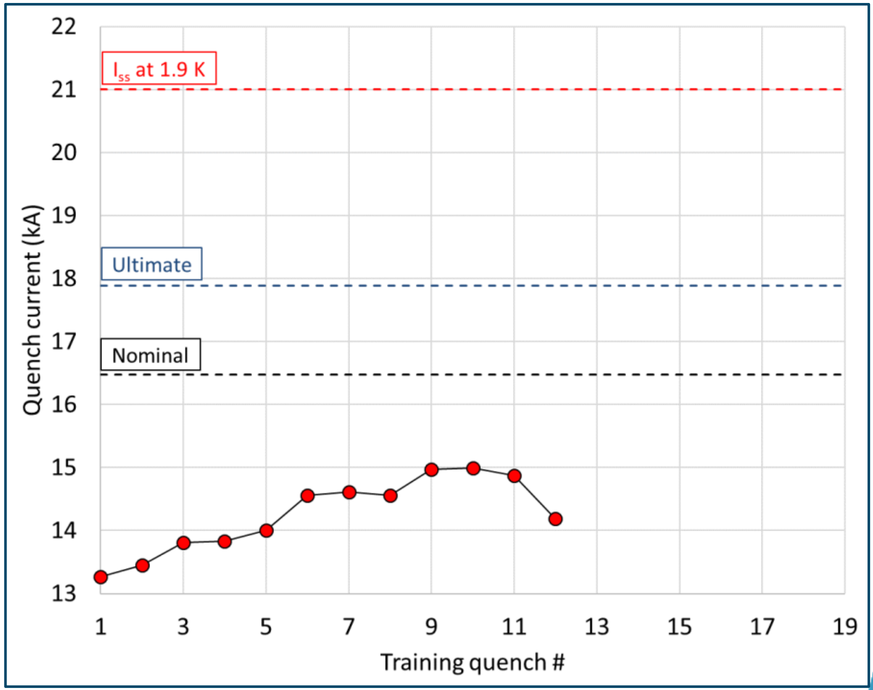
- Short was caused by a series of events
  - Coil 5 impregnation was poor in the short area:
    - Increased possibility of helium trapped after cold test
  - Between quench 1 and 2, magnet hi-potted with high voltage (2.5 kV) at 293 K, after helium exposure
- Design weakness is excluded



MQXFAP2

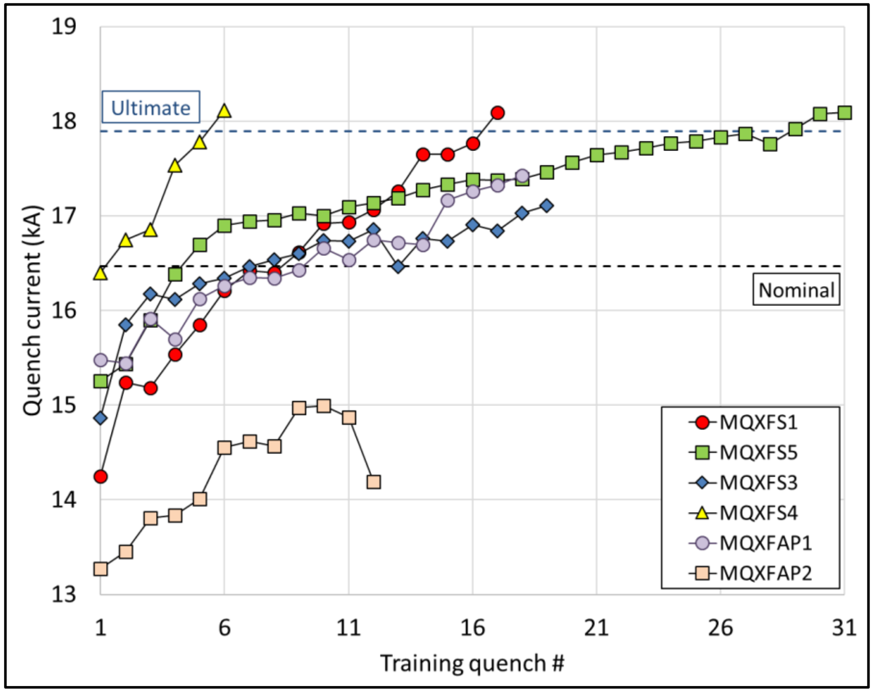
- 2nd generation coils, 4.2 m, RRP 108/127
- Same pre-load as MQXFAP1
- Test in progress

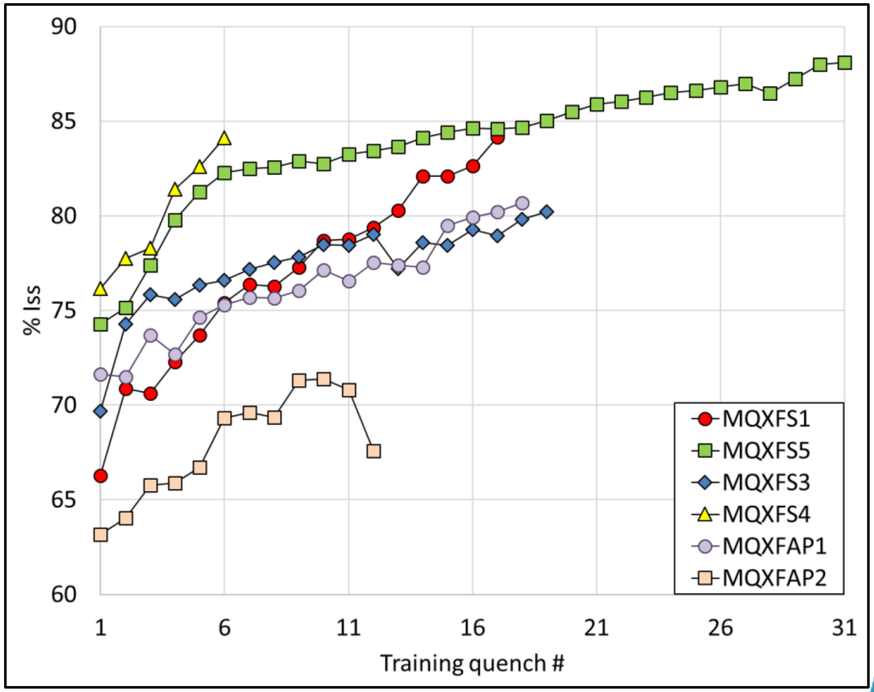




Comparison/conclusions

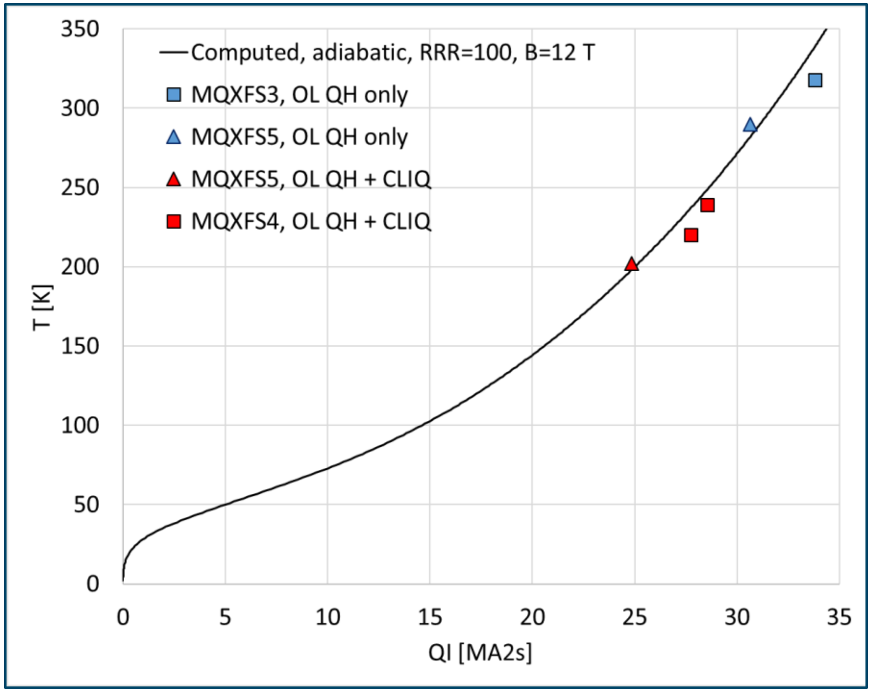
- All short models and MQXAP1 reached I_{nom}
- 3 short models reached I_{ult}
  - MQXFS3 only at high ramp-rate and MQXFAP1 stopped by electrical short
- MQXFS4 fastest training (6 quenches to 85% of I_{ss})





Quench protection

- Inner layer quench heaters abandoned
  - Issue of delamination not solved
- Protection with outer layer QH and CLIQ



Next steps

- Assembly of MQXFBP1

- Assembly of MQXFS6: PIT with bundle

Appendix

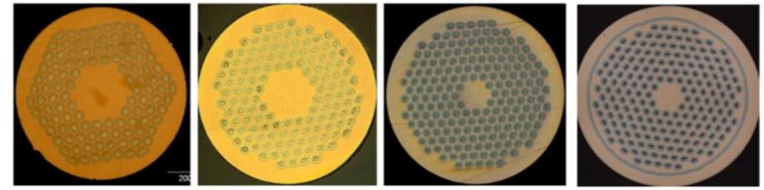
Conductor and cable

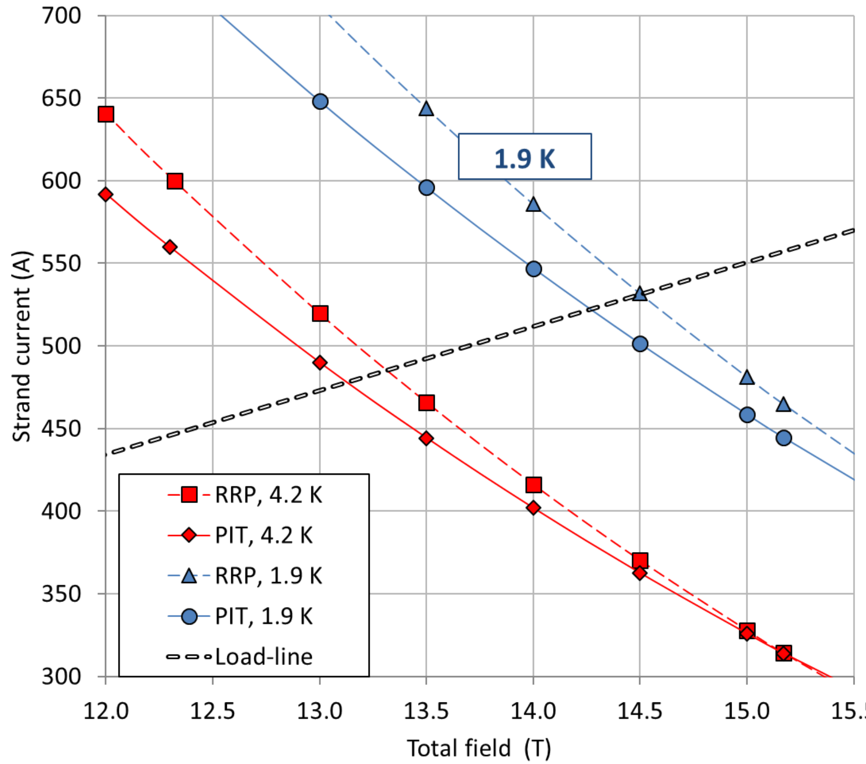
- Two final strands
  - RRP 108/127 (MQXFA/B)
  - PIT 192 with bundle barrier (MQXFB)
- Also used
  - 132/169 and PIT without bundle barrier

- So, I_{nom} correspond to
  - 77% of I_{ss} for RRP
  - 79% of I_{ss} for PIT

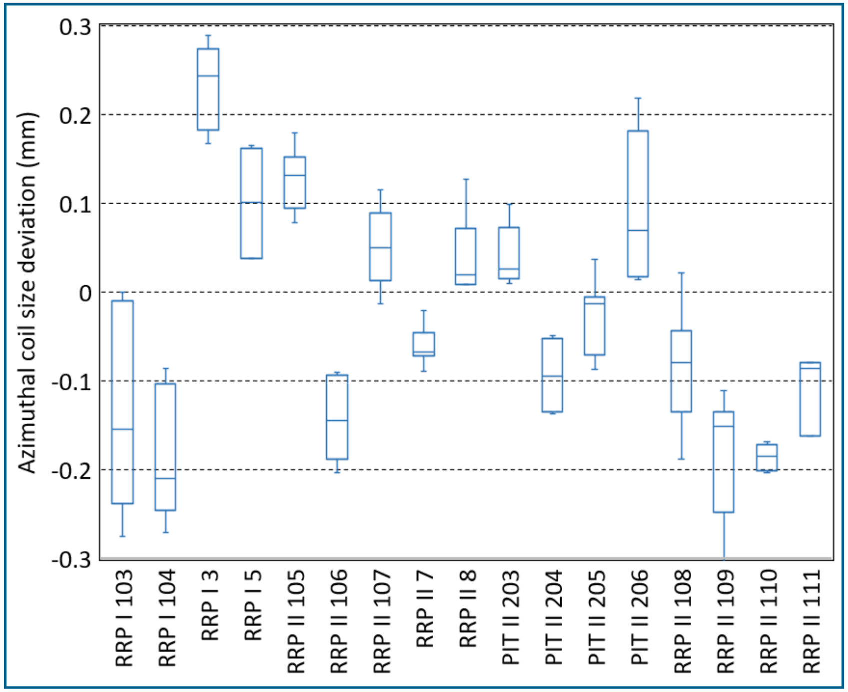
- And I_{ult} → 84-86%

- 1st and 2nd gen. cables
  - From 0.55° to 0.40 ° keystone angle

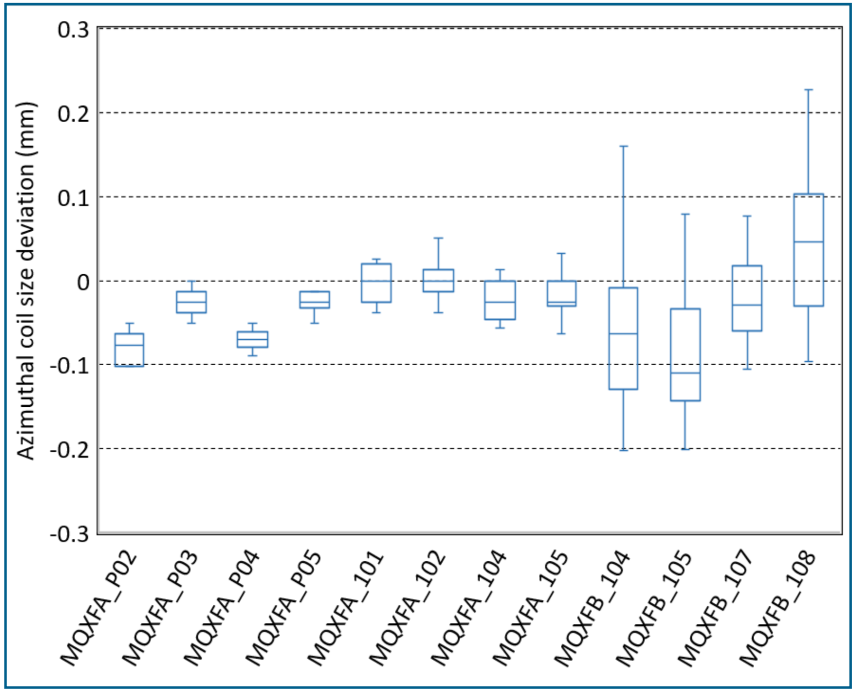




CMM



Azimuthal coil size deviation (mm)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
RRP I 103
RRP I 104
RRP I 3
RRP I 5
RRP II 105
RRP II 106
RRP II 107
RRP II 7
RRP II 8
PIT II 203
PIT II 204
PIT II 205
PIT II 206
RRP II 108
RRP II 109
RRP II 110
RRP II 111



Azimuthal coil size deviation (mm)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
MQXFA_P02
MQXFA_P03
MQXFA_P04
MQXFA_P05
MQXFA_101
MQXFA_102
MQXFA_104
MQXFA_105
MQXFB_104
MQXFB_105
MQXFB_107
MQXFB_108

Field quality