Preload characterization of short models of MQXF the Nb_3Sn Low-β Quadrupole for the Hi-Lumi LHC

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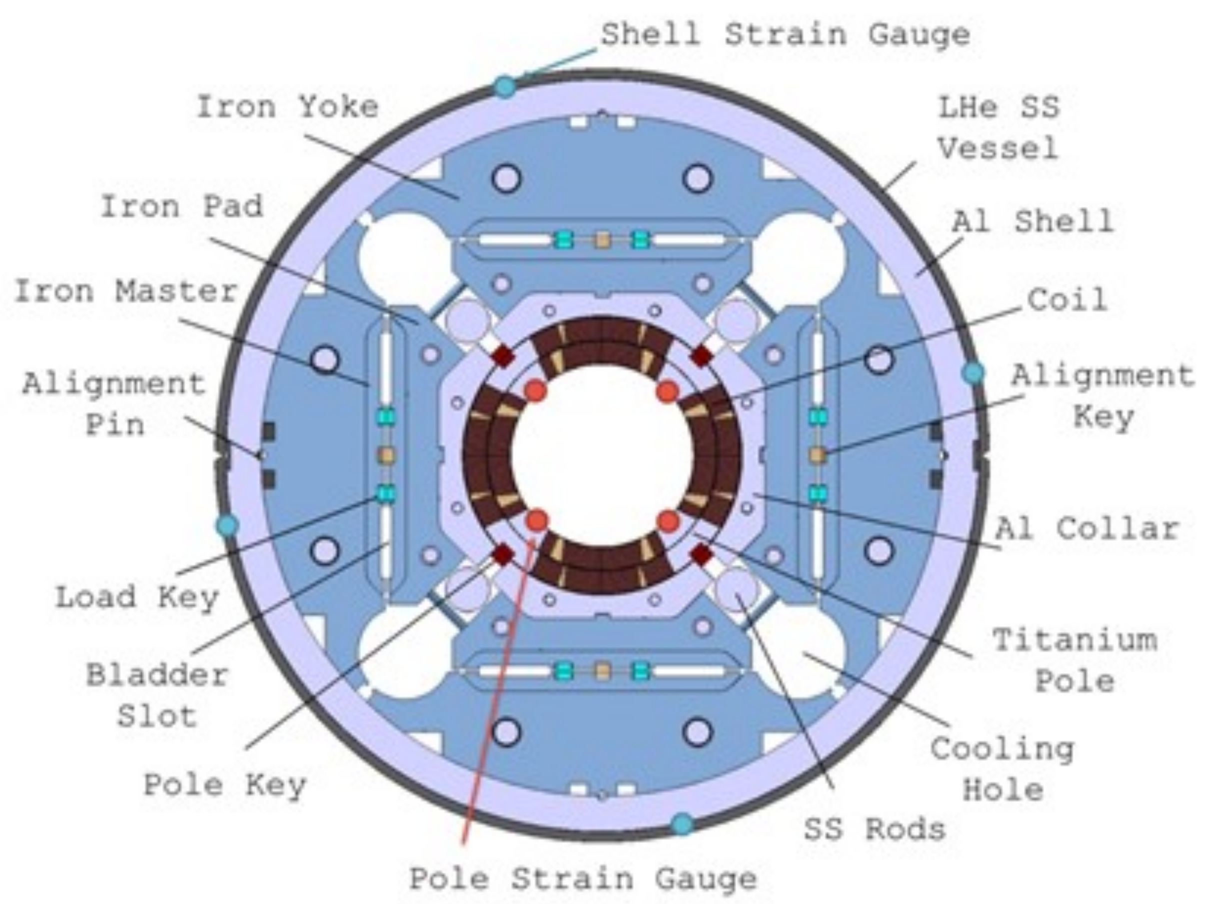
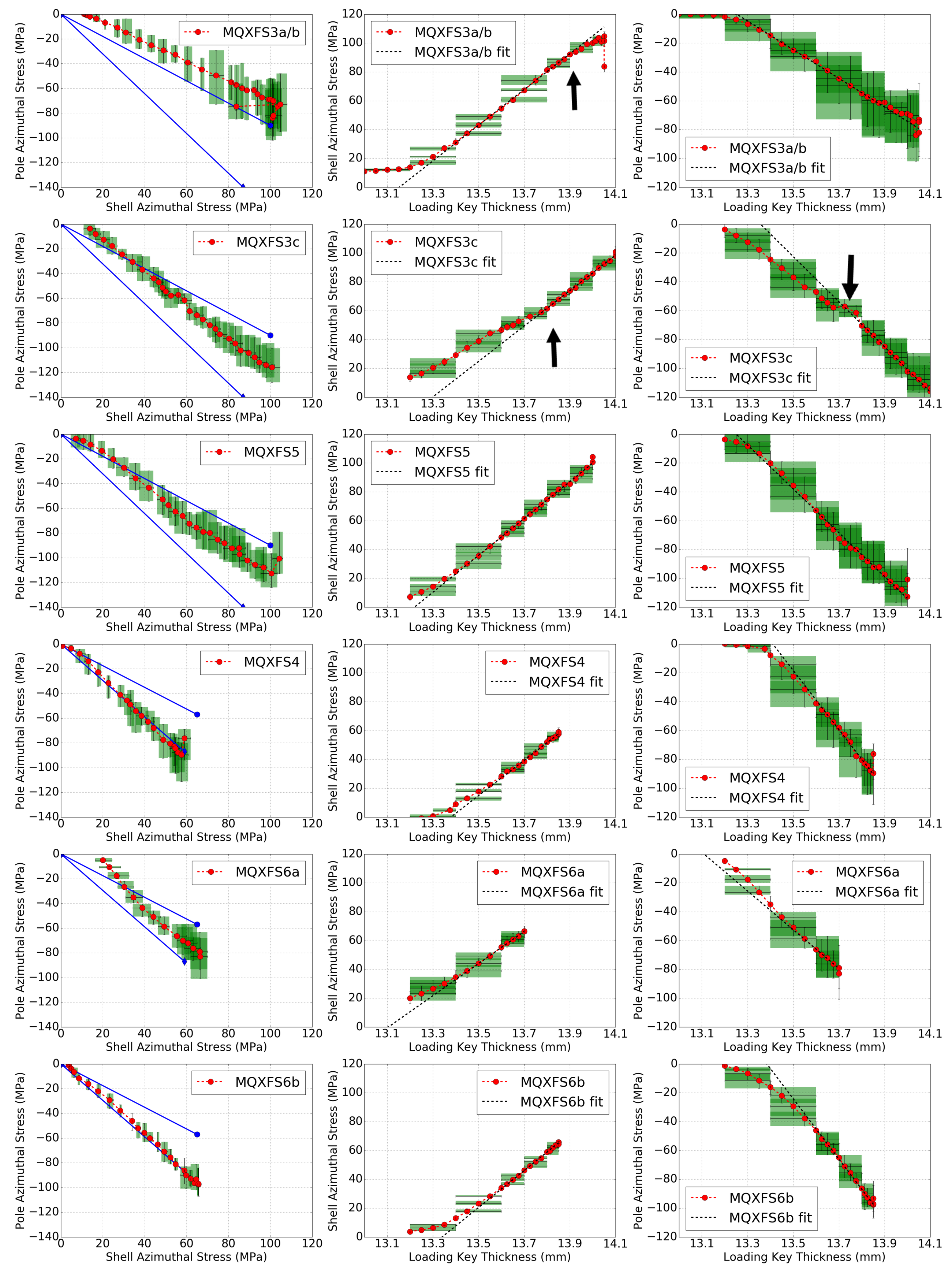
Abstract

MQXF is the Nb_3Sn Low-β Quadrupole magnet that the HL-LHC project is planning to install in the LHC interaction regions in 2026 as part of an upgrade to increase the LHC integrated luminosity by about a factor of ten. The magnet will be fabricated in two different lengths: 4.2 m for MQXFA, built in the US by the Accelerator Upgrade Project (AUP), and 7.15 m for MQXFB, fabricated by CERN. In order to qualify the magnet design and characterize its performance with different conductors, cable geometries and pre-load configuration, five short model magnets, called MQXFS, were fabricated, assembled and tested. The last model, MQXFS6, used a new powder-in-tube (PIT) superconducting wire, featuring a bundle barrier surrounding the filaments. The coil and the support structure were equipped with strain gauges and optical fibers to monitor strain during assembly, cool-down and excitation. In this paper we further develop the conventional azimuthal preload analysis and introduce a new set of tools for MQXF coil pack characterization which we use to analyse the behaviour of MQXFS6 room temperature preload and to reanalyse all the short models tested at CERN. A comparison is made between all the studied magnets revealing new characterizing preload parameters

Introduction

- MQXF is one component of the HL-LHC upgrade
- Quadrupole magnet characterized with 132.6 T/m, 150 mm aperture, 11.4T peak field
- MQXFA 4.2 m (AUP) and MQXFB 7.15 m prototypes
- So far MQXFS1/3/4/5 1.5 m short models built for testing
- Azimuthal preloading: bladders and keys
- Loading key size determines the level of stress
- Pole key ensures coil-collar alignment but intercepts collar movement
- Pole key clearance one of the key parameters in azimuthal preloading
- In MQXFS4 pole key clearance is ensured and it exhibits the lowest training of all the short models
- MQXFS6 is assembled with powder-in-tube (PIT) coils, fully tested, disassembled and preloaded again (two limiting coils replaced with coils from MQXFS5)
- Respectively the first and second assembly are referred as MQXFS6a and MQXFS6b

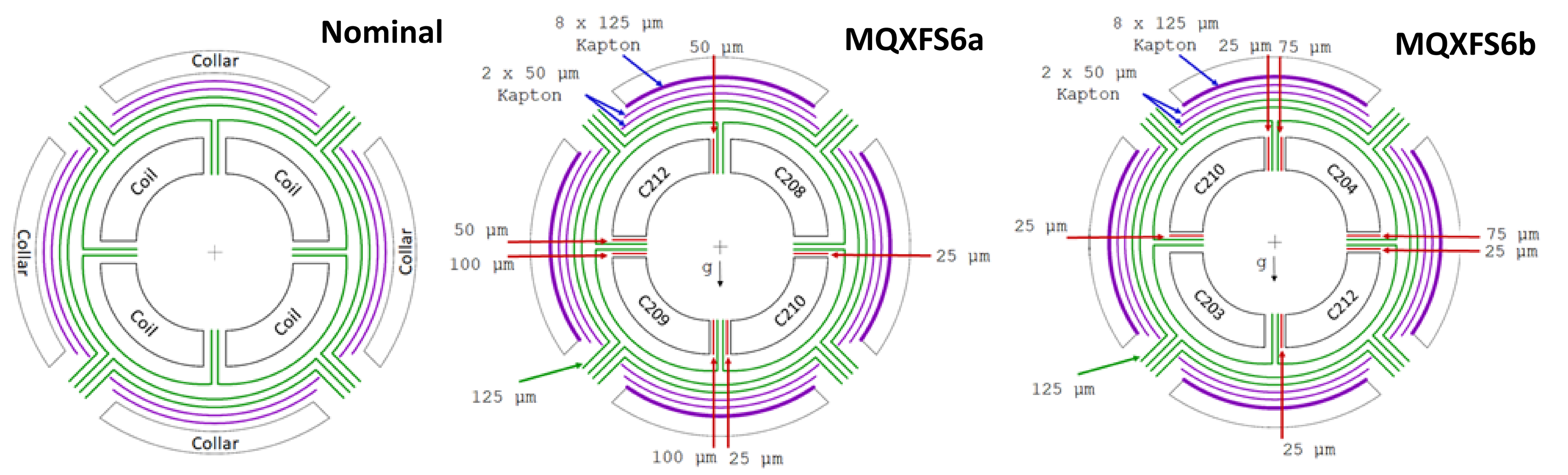




	MQXFS3a/b	MQXFS5	MQXFS3c	MQXFS4	MQXFS6a	MQXFS6b
Coil pack (um) (exp. shimming)	-105	-112	-187	-263	-118	-118
TF slope (MPa/MPa)	-0.8	-1.2	-1.3	**-1.7**	-1.2	**-1.6**
Shell contact key (mm)	13.15	13.22	13.3	13.38	13.11	13.34
Pole contact key (mm)	13.25	13.25	13.36	13.41	13.11	13.38
Contact key offset (um)	-100	-30	-60	-30	0	-40
Pole stress offset (MPa)	10	5	10	6	0	8
Coil pack (um) (contact keys)	-150	-220	-300	**-380**	-110	**-340**

Shimming

- In MQXF coils are housed with collars, free space is designed in between the touching parts
- Tight fitting achieved with shimming that can be adjusted in case the produced parts don't respect the nominal dimensions



Refined TF and KPs

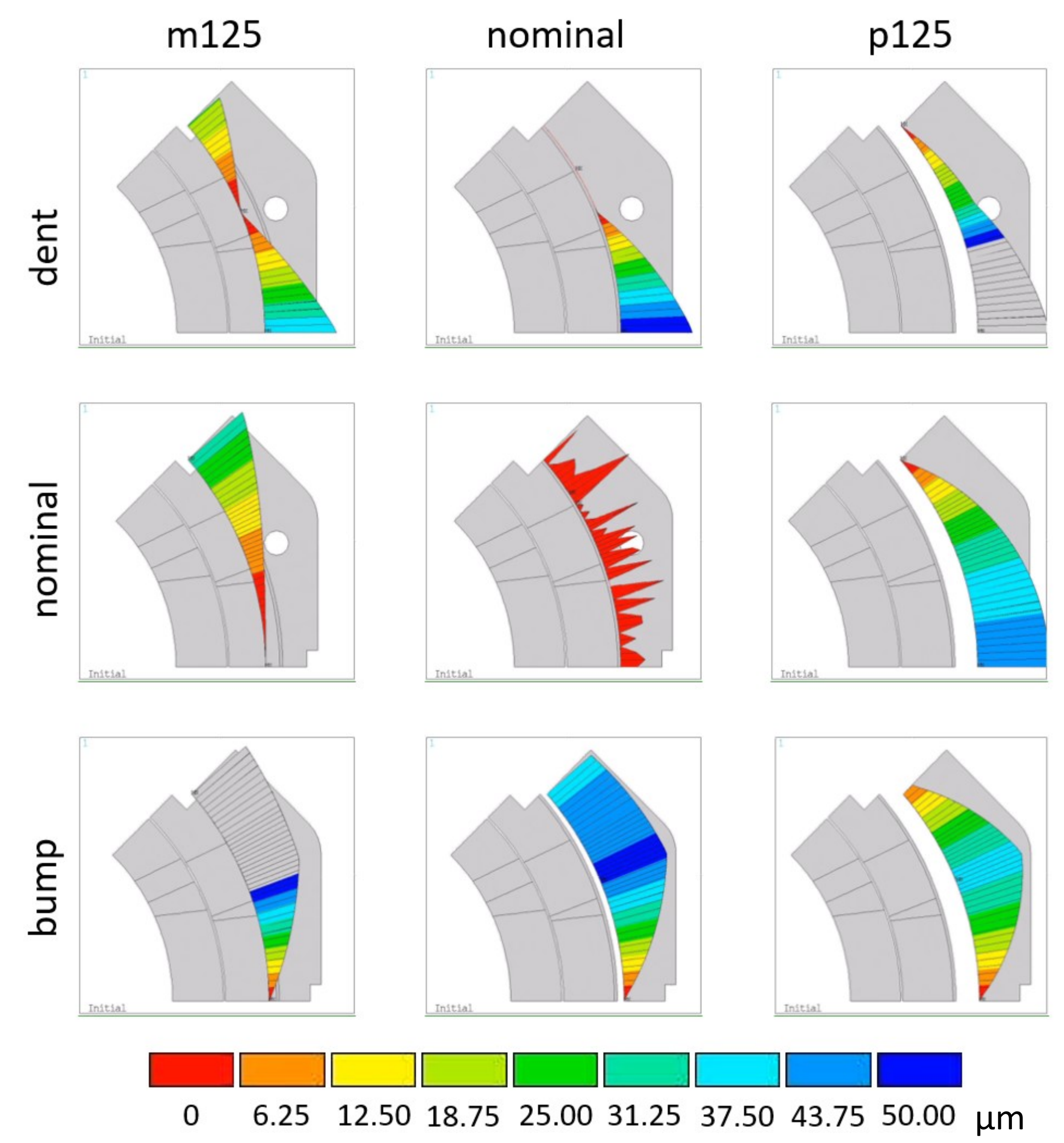
- Preload transfer function can be produced by taking into account each loading key increment instead of full cycles (convention)
- Additionally azimuthal stress vs key thickness, so called key plot (KP), is introduced and studied
- Key plots can be produced for both shell and pole
- Linear fit is done for the key plots and based on it several interesting parameters can be derived as follows
- **contact keys**: loading key thickness that generates a reaction on the shell or pole (shell and pole contact key), is defined as the intersection of horizontal axis and the linear fit
- **contact key offset**: the difference of shell and pole contact keys (interception or coil bending)
- **coil pack size**: the difference of nominal contact key and shell contact key
- **shell slope**: rigidity in terms of contact key and shell stress
- **pole slope**: rigidity in terms of contact key and pole stress

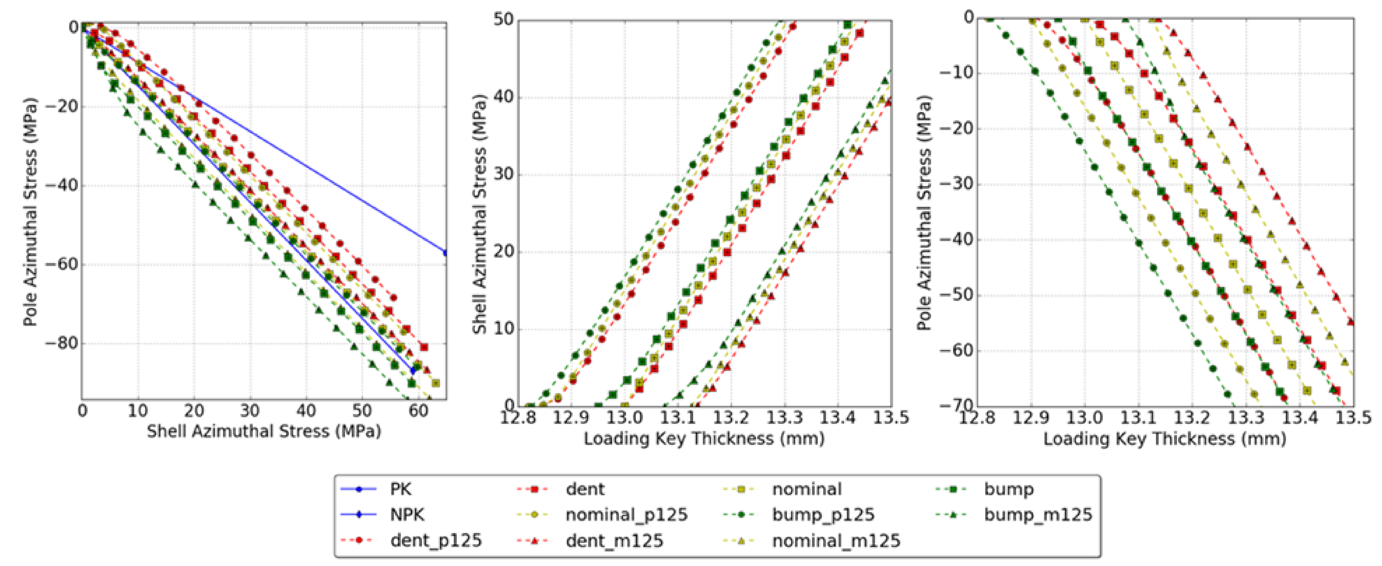
Azimuthal preload TF-KP analysis

- All MQXFS magnets produced at CERN are reanalyzed
- MQXFS3a/b non-linear pole key plot hints at pole key deformation -> MQXFSb shifted to pk line and pole key broken after the test
- MQXFS3a/b only one with no clearance -> TF above the pk line and contact key offset is the highest
- MQXF3c slope change that could be a late pole key—collar contact
- MQXFS4 and MQXFS6b are the optimal npk cases: pole key clearance ensured and small coil packs (smaller than nominal and smaller than expected from the shimming plan)
- Contact key offsets motivate the LQ on MQXF study
- As the coil packs are smaller than nominal the LQ effect on MQXF study suggests a dent on the mid-plane

The LQ effect on MQXF

- Sometimes coil and collar curvatures are incompatible (the LQ effect)
- The effect is studied with a modified MQXF 2D reference model
- Contact elements used to define a gap profile in between the collar and coil
- Three basic profiles are defined: dent, nominal and bump (mid-plane)
- Each profile modified with removing or adding a 125 µm Kapton layer





TF and KPs analysis for LQ effect on MQXF

- Sometimes coil and collar curvatures are incompatible (The LQ effect)
- A 50 µm dent or bump on the mid-plane offsets the TF curve by a positive or negative constant equivalent of that of 125 µm adding or removing
- The dent or bump can be compensated by removing or adding
- Shell contact keys are sensitive to adding or removing but not to dent or bump -> can be used to determine the coil pack size
- A 50 µm dent or bump lead to –35 µm or +35 µm offset
- A mid-plane dent or large coil packs could explain the observed offsets