WG2 - Cost Assessment and Reduction

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Motivation

In order to enable the next generation of High Energy Hadron Colliders, the cost drivers of superconducting magnets using Nb_3Sn conductors must be identified and addressed.
Therefore, the goals of this working group are to:

- Understand the cost drivers of high field accelerator magnets, and explore ways to control them, including through industry engagement;
- Provide feedback pertinent to coil and magnet fabrication technology aiming at cost reductions, possibly also through industry engagement.

Method

This section presents a cost analysis of the Nb_3Sn low-beta quadrupoles for High-Luminosity LHC. This cost analysis is limited to the magnetic element (the "MQXFA magnet" according to the HiLumi nomenclature) without taking into consideration cold mass and cryostat, because the entire cryostat and some cold-mass parts will be provided by CERN. Figure 1 depicts MQXFA magnets, cold mass, and cryostat for the Q1/Q3 elements of HL-LHC.
The data used for this analysis were presented by the US LHC Accelerator Upgrade Project at the CD-1/3a Review. Although the project was not yet baselined at the time of this review, this set of data presents a realistic, all-factors-included picture of the present cost of Nb_3Sn magnets from a US perspective (i.e., including personnel, yield assumptions, and some risk mitigation factors). It should be noted that when this estimate was made some labor (estimated as Level of Effort) was included in the Integration and Coordination effort and therefore is not taken into account in this analysis.

Figure 2.1: MQXFA magnets (top), cold mass (middle) and cryostat (bottom) for the Q1/Q3 elements of the HL-LHC Inner Triplet.

Results

The results of the cost analysis are presented in Table 2.1. The numbers in bold represent subtotals per magnet, whereas the unbolded numbers represent the cost per single cable or coil. The cost per cable (item 1) includes strand procurement and QC, cable fabrication, insulation, and QC. The cost of coil fabrication (item 3) includes the additional costs (i.e. nothing already included in item 1) to obtain a completed coil: winding, curing, reaction, and epoxy impregnation, and all M&S for these fabrication steps. Item 5 includes structure procurement and QC, structure subassemblies, and coil structure assembly leading up to the final magnet and final QC. Item 6 shows the cost estimate for a production vertical test assuming 20 training quenches at 1.9 K, magnetic measurements, two thermal cycles, and a few quenches for temperature and ramp-rate dependence study. Item 7 was obtained by computing the cost of all the yield assumptions (additional cables, coils, magnet assemblies, and vertical tests) included in the preliminary project baseline and dividing it by the number of magnets.
Items 6 and 7 may be grouped together because they are different strategies for addressing the same issue: some components (cables/coils/magnets) may fail and need replacement. In the rest of this analysis, we identify this group as "risk mitigation," and has a total cost of about $1M.

Table 2.1: Cost analysis of MQXFA magnets by US LHC Accelerator Upgrade Project

Item	Part	Labor (k$)	M&S (k$)	Total (k$)
1	One insulated cable	30	210	240
2	**Four insulated cables**	**120**	**840**	**960**
3	One coil fabrication (w/o cable cost)	210	60	270
4	**Four coil fabrications (w/o cable cost)**	**840**	**240**	**1,080**
5	**Structure procurement & magnet assembly**	**220**	**820**	**1,040**
6	**Magnet vertical test at BNL**	**290**	**110**	**400**
7	**Yield assumptions (cost per magnet)**			**519**
	TOTAL per MQXFA magnet			**3,999**

Table 2.1 shows that the total cost of an MQXFA magnet, including risk mitigation features, is $4M.
This total cost can be divided into four parts, each costing about $1M: four insulated cables; four coil fabrications; structure procurement and magnet assembly; and risk mitigation. M&S cost is the dominant component of Item 2 (i.e., conductor procurement) and Item 5 (i.e. structure parts procurement); labor cost is the dominant component of Item 4 (i.e coil fabrication labor time).

Conclusions

The MQXFA cost analysis has shown that there is not a single main cost driver for these magnets. Even if other Nb_3Sn accelerator magnets may have other cost distributions, the big picture is not expected to change significantly. This observation may be employed to reach the following conclusion: **In order to achieve significant cost reductions, the next generation of Nb_3Sn accelerator magnets must be developed with the goal of cost reduction in the following areas: 1) conductor procurement; 2) labor for coil fabrication; 3) structure components procurement; and 4) risk mitigation**.

The plan presented in this report aims at addressing each of these cost drivers by:

1. Significantly improving conductor performance and reducing magnet operation margins in order to reduce conductor volume.
2. Changing coil fabrication processes in order to significantly reduce labor time per coil (industrial automation may be explored for long-term projects).
3. Developing magnet structures with fewer parts, leading to cost savings in production.
4. Increasing the reliability of coil/magnet fabrication in order to decrease risk mitigation factors.