Results on Quality Factors of 1.3 GHz Nine-Cell Cavities at DESY.

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Abstract

Superconducting cavities made of niobium are the basis of many particle accelerators around the world. Besides the quest for high accelerating fields for projects like European XFEL and the International Linear Collider, the quality factor, a measure for the resistance and hence the ohmic losses, is of importance, as it eventually determines the cryoplant size and its costs of operation. Especially for accelerators operating in continuous wave mode, the dynamic heat load generated by cavity operation exceeds the static heat load by far and thus requires minimisation. To investigate the current quality factor performance at various fields of 1.3 GHz cavities at DESY, the test results of some 50 recent cavities with state-of-the-art treatment have been examined regarding surface treatment and material.

Superconducting 9-cell 1.3 GHz XFEL-type cavity

Introduction

The minimisation of the ohmic losses in superconducting cavities during operation is of importance, as the operating temperature of T = 2K or loss is demanding in terms of providing a fair amount of liquid helium as coolant. A measure for the surface resistance and hence the dissipated power is the unloaded quality factor Q_0. The dissipated power P_{diss} calculated by:

$$P_{diss} = \frac{E_{acc}^2 l^2}{(R/Q)Q_0}$$

The parameters are as follows (values given are for the XFEL-type cavity):

Accelerating field	E_{acc}	*to be measured*
Active length	l	1.038m
Geometric factor	R/Q	1030 Ω
Unloaded quality factor	Q_0	*to be measured*

Dataset

Cavity production series

Only recent cavity productions (starting from group 5) with state-of-the-art treatment taken, as marked in the table on the right:

> marked in gray: large grain material
> marked in blue: fine grain material

Excluded:

> groups 0-4: early production
> group 7: manufactured of 3-cell hydroformed units
> group 9: new equator welding technique (Z160-Z162)

In addition, results of 4 reference cavities of each cavity vendor providing cavities for the European XFEL have been examined

Surface treatments

There are three types of surface treatments applied at DESY

> EP: electropolished
> BCP: buffered chemically polished
> EP+: electropolished surface with light BCP added

Data analysis

Quality factor curves were evaluated after processing (if applicable) of multipacting or other effects.

The data of the cavities has been taken into account until either thermal breakdown or the onset of radiation (>10^{-4} mGy/min), thus towards higher fields the underlying dataset becomes smaller

The plots show the averaged quality factor of the full dataset including the standard deviation as error bars. The measurement uncertainties for each cavity test are below 10%.

Overview of pre-XFEL 1.3 GHz 9-cell cavities at DESY

Production group	Amount of cavities	Cavity serial number
~~0~~	~~2~~	~~P-1, P-2~~
~~1~~	~~27~~	~~D1-D6, S7-S12, A13-A18, C19-C27~~
~~2~~	~~27~~	~~S28-S36, D37-D42, C43-C48, Z49-Z54~~
~~3~~	~~27~~	~~AC55-AC81~~
~~4~~	~~30~~	~~Z82-Z111~~
5	3	AC112-AC114
6	35	AC115-AC129, Z130-Z144, AC146-AC150
~~7~~	~~3~~	~~Z145, Z163, Z164~~
8	8	AC151-AC158
~~9~~	~~4~~	~~AC159, Z160-Z162~~

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Surface treatments (large grain cavities)

This analysis allows comparison of the quality factor for all three surface treatments (EP, BCP, EP+) applied at DESY, since the 11 large grain cavities have been treated and tested for this reason.

Only 4 cavities got an EP+ treatment. At fields above E_{acc}=30 MV/m, statistics for EP is very low (2/1).

Results:

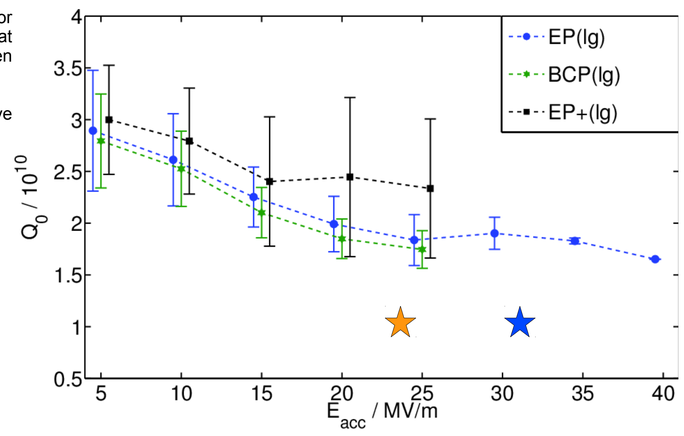
> Offset for EP+: one cavity was strongly overcoupled and yielded too high quality factors

> Quality factor requirements for XFEL easily reached

> For fields up to E_{acc}=15 MV/m: Q_0 well above 2E10

> For higher/highest fields Q_0 above 1.5E10

> Q_0 evolution similar for all surface treatments



Averaged quality factors for large grain cavities

Q_0 exceeds specifiations for XFEL/ILC

Surface treatments (fine grain cavities)

There are 19 EP cavities and 18 EP+ cavities, only 6 cavities have been tested with both surface preparations.

Besides these cavities 4 reference cavities (RCVs) from each XFEL cavity vendor have been examined.

Results:

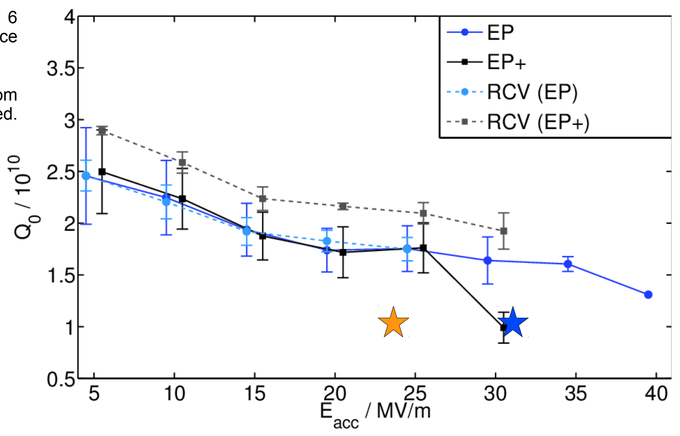
> Similar evolution of quality factor for all datasets

> Quality factor requirements for XFEL easily reached

> Q_0 > 1.5E10 for accelerating fields up to 25 MV/m

> RCV show similar performance as earlier cavities

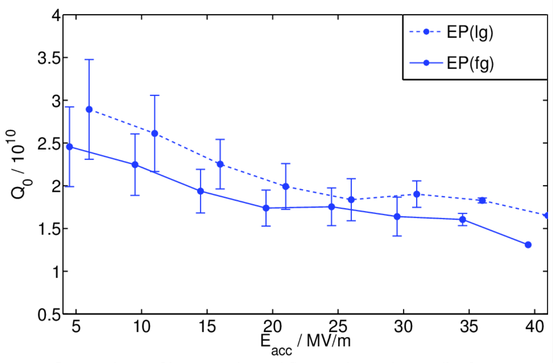
> Cavities outperform accelerator specifications



Averaged quality factors for fine grain cavities

Q_0 exceeds specifiations for XFEL/ILC

Large and fine grain Nb



Comparison of large grain and fine grain cavity quality factors

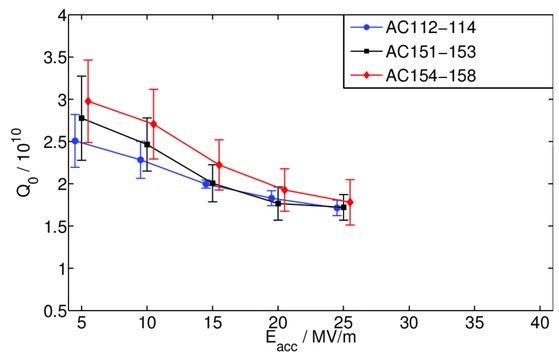
Results:

> Large grain cavities yield about 20% higher quality factor up to E_{acc}=20 MV/m → about 1/6 less dissipated heat for large grain

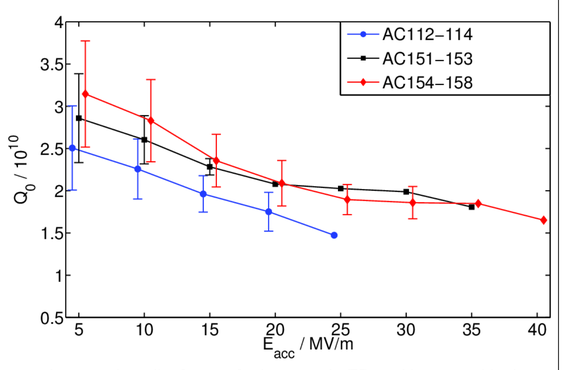
> Above 20 MV/m smaller difference: other mechanisms at work

> Large grain still not an option for large scale production

RRR



Averaged quality factors for large grain BCP cavities sorted by ingot



Averaged quality factors for large grain EP cavities sorted by ingot

The following RRR values have been measured at the niobium sheets before manufacturing the cavities:

> AC112-AC114: RRR=505
> AC151-AC153: RRR=406-438
> AC154-AC158: RRR=340-355

Results:

> Sequence of ingots and quality factor trend similar for both surface treatments

> Similar quality factors for both treatments

> Higher quality factor for lower RRR as expected

Conclusion Acknowledgements

About 70 tests of superconducting 1.3 GHz 9-cell cavities at DESY have been examined:

> Large grain cavities feature 10-20% higher quality factors than cavities made of fine grain material → expected

> Cavities made of niobium sheets with higher RRR yield slightly lower quality factors → expected

> No significant difference in quality factors for different surface treatments

The dataset available shows promising results regarding the specifications of current large scale accelerator projects, which require $Q_0 > 10^{10}$. Most of the cavities also meet the requirements for continuous wave accelerators at lower accelerating fields ($Q_0(E_{acc} < 20$ MV/m$) > 2x10^{10}$).

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