



2nd Sound as quench localisation tool

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Abstract

Superconducting 1.3 GHz cavities have been used successfully for several years in the FLASH accelerator at DESY. They will be used for the European XFEL and are the cavities of choice for the ILC. Worldwide a considerable effort is made to push the average accelerating gradient beyond 30 MV/m. Various diagnostic tools for localising defects that cause heating and thermal breakdown, also known as “quench”, have been developed. The software for quench localisation using the 2nd Sound in superfluid Helium, will be introduced in this report.

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1 Introduction

The fabrication process of superconducting cavities has been developed and optimised over the past 15 years, since the main obstacle reaching of gradients exceeding 30 MV/m is the local thermal breakdown of superconductivity due to surface structures. A former report [1] introduces the optical inspection of the inner surface of the cavity to find such surface structures. The defects found by the optical inspection do not necessarily lead to quenching, so the final verification has to be done in a cold vertical test using time consuming temperature mapping [2] or quench localisation via second sound [3].

2 Second Sound

The cryogenic measurements on 1.3 GHz SRF cavities take place at temperatures below 2K in liquid Helium below the λ -point. This leads to a mixture of He I and superfluid Helium (He II) inside the cryostat. If energy is deposited in the helium vessel, e.g. by a quench, the phase transition of He II to He I propagates as an entropy wave, the so-called Second Sound. The amplitude of the Second Sound signal and the propagation velocity of the Second Sound depend on the temperature of the helium bath. This wave can be observed with Oscillating Superleak Transducers that operate like condenser microphones with a porous membrane to allow He II flow while He I will be blocked because of its viscosity. With a DC voltage of 120 V applied to the transducers, special safety requirements had to be taken into account, such as special cabling and shielding of the amplifier electronics. With a set of eight OSTs one can cover the entire surface of a cavity and measure the propagation times of the Second Sound. With the known propagation velocity v in a range of 16- 20 m/s at 1.4-2 K at least three measured signals are required for triangulation. Measurement errors affect the reconstruction of the quench position; the calculated coordinate is typically not located on the surface of the cavity. A better position can be found with a constraint fit on the cavity surface. The resolution of this method is estimated to be around several millimeters, which is a large improvement compared to temperature mapping (about 1 cm).

3 Quench Localisation Software

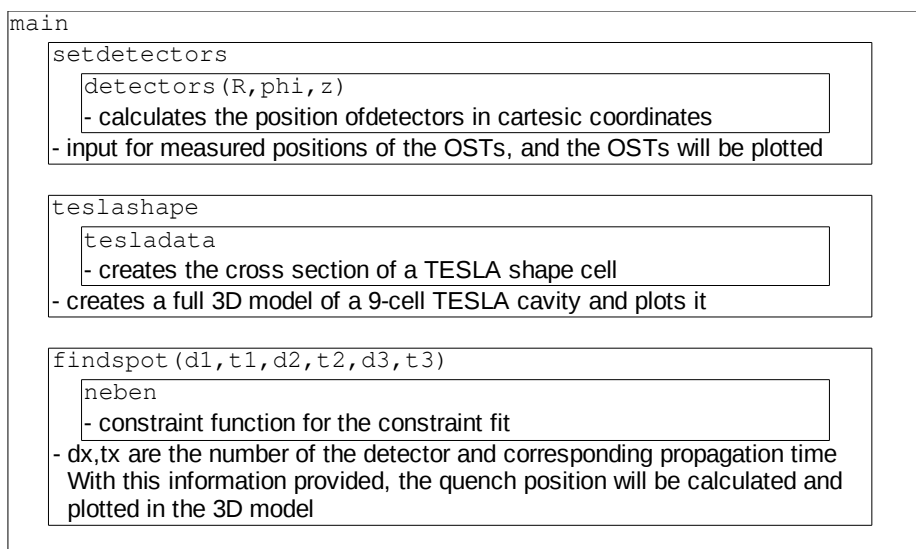


Figure 1: Program flow of the quench localisation software

The localisation of the quench on the cavity surface is done with a MATLAB code (see appendix), using line-of-sight calculation, as most of the quenches occur at or near the equator. It is based on a χ^2 minimization with geometrical constraints. A key requirement is the positioning and precise measurement of the OST positions at the cryostat insert, in particular to place the plane of the membrane tangentially to the cavity surface at the equator. The coordinates have to be provided to the program in a convenient set. One needs the offset from the equator of cell 5, which is used as the coordinate reference, in the z-direction, the azimuthal angle and the radial distance from any equator of the cavity to the centre of the membrane. At the vertical test a trigger signal for the quench, e.g. the reflected power of the input coupler is needed to determine the propagation times for the Second Sound. The signals of all transducers used in the vertical test have to be acquired for about 100ms after the quench to be sure to record the signal. After the readout of the propagation times one feeds the program (`main.m`) with the following information: Number of detector and corresponding propagation time. The propagation velocity can also be adjusted in the `findspot.m` file. After running the `main.m` file, a three dimensional plot of a 9-cell cavity including the OSTs and the calculated quench location will show up. In the MATLAB command window the quench position will be given in cylindrical coordinates for a precise location on the “real” cavity. The program flow is shown in Figure 1.

4 Conclusion

The major step for the automated quench localisation using the 2nd sound in superfluid Helium is done by providing a code for the calculation of the quench position. Further steps will be an automated signal analysis to reach a “single-step” measurement.

Acknowledgement

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References

- [1] S. Aderhold et al., “Cavity Process”, ILC-HiGrade-Report-2010-005-1
- [2] D. Reschke, “Analysis of Quenches using Temperature Mapping in 1.3 GHz SCRF Cavities at DESY”, Proc. of LINAC '08, Vancouver, Canada
- [3] F. Schlender et al. “Progress on Diagnostic Tools for Superconducting High-Gradient Cavities”, Proc. of LINAC'10, Tsukuba, Japan

Appendix

main.m

```
function main
% Get detector positions and plot the detectors in the 3D plot
setdetectors
% Create TESLA cavity and plot it
teslashape
%Set detectors with a signal and the corresponding TOF tracecalc(detno,TOF
%in ms, detno, TOF in ms, detno, TOF in ms)
findspot(5,11.3,7,17.4,8,9.1)
```

setdetectors.m

```
function setdetectors
% enter detector positioning data
% PLEASE NOTE: The coordinates of the detectors have to be given related to
% the equator of cell 5 in cylindrical coordinates. The angle is measured
% counterclockwise related to the coupling tube and up to 360 degrees.
setappdata(0,'detectorposition',[ ]);

% set detector data (radius reduced by equatorial cav. radius,angle,z)
% will be recalculated in function "detectors"
detectors(100,324,-225.8)
detectors(100,325,240.8)
detectors(125,261,-344.2)
detectors(120,260,122.4)
detectors(118,105,-220.8)
detectors(117,107,237.8)
detectors(90,65,-344.2)
detectors(90,66,123.4)
detpos=getappdata(0,'detectorposition');
size(detpos)
hold on

% plot detectors
for i=1:1:size(detpos,1)
plot3(detpos(i,1),detpos(i,2),detpos(i,3),'sr')
end
```

detectors.m

```
function detectors(r,p,z)
% creates the detectors
detpos=getappdata(0,'detectorposition');

% create coordinate parameters, point of origin is the center of cell #5
z0=625; % equator height of cell #5
r0=103.3; % equatorial radius of cavity

% create "real" cartesian coordinates, starting at the bottom flange of the
% cutoff tube at the power coupler side, write them in the detpos-array

[x y z]=pol2cart((p/360)*2*pi,r+r0,z+z0);
if isempty(detpos)
detpos=[x y z];
else
detpos=[detpos;x y z];
end

% write detector positions in global "variable" detectorposition
setappdata(0,'detectorposition',detpos);
```

teslashape.m

```
function teslashape
% create z- and phi-variable
p=linspace(0,2*pi,361);
z=linspace(0,1276,1277)';

% calculate 3-dim. TESLA shape
xx=tesladata(z)*cos(p);
yy=tesladata(z)*sin(p);
zz=z*ones(size(p));

% plot cavity
surf(xx,yy,zz);
axis equal;
hold on;
```

tesladata.m

```
function r=tesladata(z)
% Creates a function with the 2-dim shape of a tesla cavity with
% parameters z as r(z)

% Parameters as given by the TESLA Design paper
a=12;
b=19;
R=42;

% radius of cut-off tube
co=35;

% create the cross-section of the 9-cell cavity
r=co.*(z<=105.6);
for i=0:1:8
r=r+(((-1)*(b.^2 - ((b.^2.*(z-(105.6+i.*115.4)).^2)/
(a.^2))).^.5)+b+co).*(z>(105.6+i*115.4) & z<(116.9+i*115.4));
r=r+(4.2274*((z-(163.3+i*115.4))+243.751).*(z>=(116.9+i*115.4) &
z<(122.6+i*115.4)));
r=r+((R^2 - ((z-(163.3+i*115.4)).^2)).^.5 + 61.3).*(z>=(122.6+i*115.4) &
z<(163.3+i*115.4));
r=r+((R^2 - ((z-(163.3+i*115.4)).^2)).^.5 + 61.3).*(z>=(163.3+i*115.4) &
z<(204+i*115.4));
r=r+(4.2274*((163.3+i*115.4)-z))+243.751).*(z>=(204+i*115.4) &
z<(209.7+i*115.4));
r=r+(((-1)*(b.^2 - ((b.^2.*(105.6+(i+1).*115.4)-z).^2)/
(a.^2))).^.5)+b+co).*(z>=(209.7+i*115.4) & z<=(221+i*115.4));
end
r=r+co.*(z>(221+8*115.4));
```

findspot.m

```
function findspot(d1,t1,d2,t2,d3,t3)
% find spot on cavity surface

cv=getappdata(0,'cavity');
detpos=getappdata(0,'detectorposition');
% velocity of 2nd sound in He in m/s
v=19.9;

% get width of propagation
r1=v*t1;
r2=v*t2;
r3=v*t3;
setappdata(0,'r',[r1 r2 r3]);

% make detector coordinates more handy
p1=detpos(d1,:)';
p2=detpos(d2,:)';
p3=detpos(d3,:)';

[phi1,rho,z]=cart2pol(p1(1),p1(2),p1(3));
[phi2,rho,z]=cart2pol(p2(1),p2(2),p2(3));
[phi3,rho,z]=cart2pol(p3(1),p3(2),p3(3));

% set uncertainty sigma
sigma=0.1;

% run least squares minimisation on the ways travelled to the signals
f=@(x) ((norm(x-p1)-r1)/sigma)^2+((norm(x-p2)-r2)/sigma)^2+((norm(x-p3)-
r3)/sigma)^2
x0=[0 0 0]';
[x,fx]=fminsearch(f,x0)
x0=x;
R=61.3;r=42;
g=@(t,p) [(R+r*cos(p))*cos(t);(R+r*cos(p))*sin(t);r*sin(p)+z0];
setappdata(0,'g',g)

% run constraint fit (quench position has to be on the surface of the
% cavity)
x=fmincon(f,x0,[],[],[],[],[],[],[],@neben,[])

% plot quench location
plot3(x(1),x(2),x(3),'-r.','MarkerSize',48,'LineWidth',8,
'MarkerEdgeColor','r','MarkerFaceColor',[.49 1 .63])

% recalculate quench location in cylindrical coordinates
[theta,rho,z]=cart2pol(x(1),x(2),x(3))

function[c,ceq]=neben(x)
% constraint function for the constraint fit
R=61.3;r=42;
c=[];
R=61.3;r=42;
ceq=((tesladata(x(3))*cos(atan2(x(2),x(1))))^2+
(tesladata(x(3))*sin(atan2(x(2),x(1))))^2+x(3)^2)^(.5)-norm(x);
axis equal;
```