ABOUT ONE POSSIBLE EXPLANATION OF INFLUENCE OF MICROWAVE MAGNETIC FIELD ON QUALITY FACTOR OF SUPERCONDUCTING ACCELERATING SYSTEM

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As known the benefit of superconducting cavities for accelerator application depends on the electromagnetic field and level quality factor Q_0 which can be achieved in mass producible multicell accelerating structures. The increasing of projects with using of superconducting waveguides reflects the progress in the rf technology during the last years and in the understanding of the field and Q_0 limitation [1]. Values for the accelerating field about 10 MV per meter and for Q_0 between 10^9 and $5\cdot 10^9$ seem to be justified for cw electron accelerators but further progress on both parameters is desired for example for linear colliders. The different kinds of observed limitations have to be recognized. One of the main problems is quenching, i. e. a sudden drop of Q_0 by several orders of magnitude at comparatively low rf magnetic field strength inside resonators (~100 - 150 mT). In spite of existing a lot of experimental and theoretical investigation devoting this problem there are not enough good physical model what could explain this phenomenon.

The purpose of this paper is to develope a new model which can explaine the experimental dependence between quenching and intrinsic proporties of the pure superconductors and superconductors with defects or contaminants on the base of taking into account influence of rf magnetic field on resistance of superconductors.

It is known that electric components of microwave are very small at metal surface. It means that in any case only small part of microwave penetrates into metal and thus electric field does not cause any sufficient changing. On the contrary magnetic field is very big on the metal surface and sufficient part of it penetrates into skin depth metal δ. Thus if there are some changing after influence microwave on the metal it is a result of influence of rf magnetic field.

It is known that magnetic field have influenced upon character of electron motion, that is upon conductivity, or resistance of metal. For great part of metals, espesially for metals with closed Fermi surfaces and for metals with open Fermi surfases as corrugated cylinder transverse resistance is proportional to square of magnetic field strength H^2, i.e.

$$\sigma=\sigma_0(1+\omega_l^2\tau^2)^{-1}=\sigma_0(1+\omega_l^2/f_{col}^2)^{-1}=$$

$$=\sigma_0[1+(eHl/mcV_F]^{-1}, \qquad (1)$$

where ω_l=eH/mc- Larmor frequency, $\tau^{-1}=f_{col}=V_F/l$ - collision frequency, V_F-Fermi velosity of the electron and l -free path length [2,3]. It means that metals may possess insulator properties at high magnetic fealds.

The value l is equal to approximately 10^{-5} cm at normal temperatures. Taking into account that $\beta_F=V_F/c=(1\text{-}3)\cdot 10^{-3}$ for majority of metals, it means that at normal temperatures there are suffisient changing of resistance only at very high magnetic field. On the contrary at low temperatures the free path length increases to value of about 10^{-1}-10^{-2} cm and thus suffisient increasing of resistance is possible at comparativly small magnetic field strength.

Taking into account that real part of metal impedance at normal skin-effect is $R=(\omega\mu/8\pi\sigma)^{1/2}$ it is not difficult to obtain the expression, characterizing dependence of R as a function of H:

$$R(H_{rf})=R(0)\,[1+(\omega_l\tau)^2\,]^{1/2}=$$

$$=R(0)\,[1+(eHl/mcV_F)^2]^{1/2}. \qquad (2)$$

From (2) follows that R increases for example ten time if value $eHl/mcV_F = eHl/mc^2\beta_F=10$. It is not difficult to show that at $l \sim (5\cdot 10^{-2} - 10^{-1})$ cm, $\beta_F\sim(1\text{-}3)\cdot 10^{-3}$ R increases ten time in comparison with R(0) if rf magnetic f ield strength H_{rf}=(300-900) Oe.

As a matter of fact normal skin-effect takes place if $l<<\delta$ and thus the above-mentioned situation is not correct at anomal skin effect when $\delta<<l$ and $\delta<<V_F/\omega$. In this range of parameter real part of superconductor impedance decreases more slowly because $R_l\sim 2\sqrt{3}/9\cdot(\sqrt{3}\,\omega^2 l/3\pi^2 c\sigma)^{1/3}$ and thus

$$R_l\,(H_{rf})=R_l(0)\,(1+\omega_l^2\tau^2)^{1/3}. \qquad (3)$$

It is essential to note that in the early investigation of dependence quality-factor vs magnetic field on the base of existing magnetic fluxoides inside inpurities in superconductors allowed to obtain that Q is inversely proportional to H. From that point of view our consideration gives approximately the same results for that part of resistance, what connected with impurities and defects.

Strictly speaking there is also another part of resistance, connected with pure superconductor resistance. Let us consider that part of it more thoroughly. It is known that real part of impedance of pure superconductor or resistance of it at frequency ω R_s depends on correlation between such parameters of material as temperature T, width of energetic gap 2Δ and frequency. For microwave cavities usually there are following dependence between above indicated parameters: $\hbar\omega \ll k_BT \ll \Delta$ where $\hbar$ and k_B -Plank and Boltzman constants. For that region [4]

$$R_s/R_l=(2/\pi)^{4/3}(\hbar\omega/2\Delta)^{4/3}(2\Delta/k_BT)\times$$

$$\times\ln(4k_BT/1.78\hbar\,\omega)\exp(-\Delta/k_BT). \qquad (4)$$

Now there are many data [4], what indicate that width of energetic gap depends on rf magnetic field as

$$\Delta(H_{rf}) =\Delta(0)\,(1- H_{rf}^{\,2}/2H_{cr}^{\,2}), \qquad (5)$$

where H_{cr} -critical magnetic field of superconductor. Taking into account that $\Delta(0)/k_BT \gg 1$ it means that enough small rf magnetic field influences on resistance of superconductor.

Thus on the base of above consideration quality factor as a function of rf magnetic field may be written as

$$Q/Q_0=[(1-x^2/2)/(1+a^2x^2)]^{1/3}\times$$

$$\times\exp[(-\Delta(0)/2k_BT)\,x^2], \qquad (6)$$

where $a=eH_{cr}l/mcV_F$ and $x=H_{rf}/H_{cr}$.

The calculated dependence of quality factor as a function of the rf magnetic field at pure superconductor is shown in fig.1, where quality factor decreases for example ten times at x=0.45-0.60 if $b=\Delta(0)/2k_BT=1.78k_BT_{cr}/2k_B\ T=0.9T_{cr}/T\approx4$. Thus we can see the sharp decreasing of Q for pure superconductor at comparatively small values of H_{rf} and temperatures about $0.2T_{cr}$ (about at 90-110 mT at T≈2K for Nb).

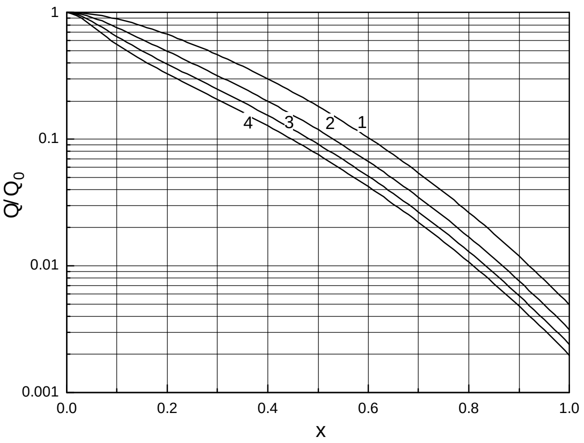

Figure 1. Dependence of quality-factor Q as afunction of rf magnetic field at b=4:
(1)-a=5, (2)-a=10, (3)-a=15, (4)-a=20.

Keeping in the mind that real superconductor consists of normal and pure superconductor parts the quality factor expression my be written as

$$Q(H)=Const./[\eta(1+a^2x^2)^{1/3}R_n(0)+$$

$$+(1-\eta)(1+a^2x^2)^{1/3}\exp(-bx^2)R_s(0)], \qquad (7)$$

where η-part of material in the normal state, $R_n(0)$ and $R_s(0)$ -resistances of normal and superconducting parts of material at $H_{rf}=0$. That formula, obtaining on the base of correct quantum consideration, allows to explain in the main particularities of the experimentally observed results.

The above-mentioned results allow to make conclusion that maximum achivable rf magnetic field level of real superconducting systems is determined not only by technological preparation methods of cavities but also by fundamental characteristics of superconductor materials and their impurities, because microwave magnetic field influences on the both parts of real superconductors resistance. Evidently the size reduction of the impurities decreases free path length of electron and in accordance with (2) it increases rf magnetic field level when there is a sufficient decreasing of nonsuperconducting part of resistance. Influence of microwave magnetic field upon width energetic gap is a main reason of a sudden decreasing of pure superconducting part resistance of the cavity.

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