Abstract

If a cavity has an infinite \( Q_0 \), 81.5% of the energy contained in a pulse incident upon the cavity is transferred into the cavity by the end of the pulse if the cavity \( Q_0 \) is chosen so that the cavity time constant is 0.796 pulse width (\( T_a \)). As \( Q_0 \) decreases, the energy in the cavity at the end of the pulse decreases very slowly as long as \( T_a \) is much less than the unloaded cavity time constant, \( T_a \). SC cavities with very high \( Q_0 \) enable us to obtain very high gradients with a low power source. At high gradients, however, we often do not attain the high \( Q_0 \) predicted by theory. Therefore, if we are interested in attaining maximum energy in the cavity, as is the case for RF processing and diagnostics, for a given available source energy there is no point in keeping the power on for longer than 0.1 \( T_a \) because the energy expended after 0.1 \( T_a \) is wasted.

Therefore, to attain high fields at moderate \( Q_0 \), pulsed operation is indicated. This note will derive the fields and energy stored and dissipated in the cavity when \( Q_0 \) is optimized for a given \( T_a \). It will show how to use this data to measure \( Q_0 \) of an SC cavity as a function of field level, how to process the cavity with the fraction of energy dissipated during \( T_a \). A cavity with an infinite \( Q_0 \) and \( Q_0 \) respectively. The change in normalized energy from the beginning to the end of the pulse, \( U' \), is:

\[
U'_c = U'((T_a)) - U'(0) = \left[ E'_c(T_a) - E'_c(0) \right]/\omega_0 \tag{1}
\]

The energy incident upon the cavity during the pulse is \( P(T_a) \). The efficiency of energy transfer into the cavity, \( \eta_c \), is:

\[
\eta_c = U'_c/U'_c = \left[ E'_c(T_a) - E'_c(0) \right]/\omega_0 \tag{2}
\]

During \( T_a \) the normalized energy dissipated in the cavity, \( \Phi_d \), is:

\[
\Phi_d = \int_0^{T_a} E'_d \, dt = T \left[ E'_d + 2(R_d - E'_a)E'_d \left( 1 - t/T_a \right) \right] + 0.5 \left( E'_d - E'_a \right)^2 \left( 1 - t^2/T_a^2 \right)/T_a \tag{3}
\]

If we start with an empty cavity, \( E'_c = 0 \), then \( E'_c = 4qQ^2(1 - t/T_a) \) and \( \eta_c = E'_c/\omega_0 \) = 2q(1 - t/T_a)^2. The energy dissipated during charging is:

\[
\Phi_{dc} = \int_0^{T_a} E'_d \, dt = T \left( E'_d - E'_a \right)^2 \left( 1 - t^2/T_a^2 \right)/T_a \tag{4}
\]

The energy dissipated during discharge is:

\[
\Phi_{dd} = \int_0^{T_a} E'_d \, dt = q \eta_c T_a \omega_0 \tag{5}
\]

The total fraction of energy dissipated during a period is:

\[
U'd = (U'dc + U'dd) = 4q^2Q^2(1 - t^2)/T_a \tag{6}
\]

\( U'dc \) also equal the fraction of average power dissipated \( P_d/P_a = P_d \) and therefore can be measured. We maximize \( \eta_c \) with respect to \( Q_0 \) at \( Q_0 = \infty \), hence \( q = 1 \), and obtain

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The cavity as measured at the top of the dewar, decreased from $10^{-9}$ to $10^{-8}$, the cavity was cryopumped. In our first test we reached a peak $E_p = 20$ MV/m. After that, presumably because it was damaged, or because of the lowered vacuum, the cavity broke down consistently at 10 MV/m. With pulsed power we could reach 40 MV/m. At 20 MV/m, radiation was observed and the pressure measured at the top of the probe increased to 10^-4 torr, mostly hydrogen. Obviously, large quantities of gases desorbed from the cavity wall and the probe, the hydrogen being the top of the iceberg. At 10 MV/m the radiation through the dewar wall plus 1/4-inch of lead was 15 mm. There was no improvement or deterioration of cw $Q_0$ and breakdown field.

We are now constructing a helium-cooled copper probe which will enable us to RF process at SC temperatures and are also preparing a high-power source that will enable us to RF process at nonsuperconducting temperatures. $E_p(\tau_a)$, $E_c(\tau_a)$, are weak functions of $\tau_a$ and therefore not suitable for its indication. $E_p$ however, varies inversely as $Q_0$, hence, it is a good indication of $Q_0$. Measuring $P_0$ at different pulse height indicates how $Q_0$ varies with field level. From a plot of $P_0$ vs field level one can deduce the field level at which $Q_0$ changes. Pulsed RF can also be used to distinguish between magnetic and thermal breakdown. The rise in temperature and hence thermal breakdown is proportional to the pulse repetition rate $n_{pp}$. We can assert that thermal breakdown does not occur when $\tau_a << n_{pp}$. Thus, if the cavity breaks down in cw, we have magnetic breakdown, and it it breaks down at high repetition rate the breakdown is thermal.

Operation of SC Cavities with Pulsed RF

To enable one to chose which system of pulsed and superconducting combinations to use we determine the overall system efficiency $\eta_{sys}$ which is defined as the ratio of $E_{o}^{\tau_a}$ to the input energy $E_{in}^{\tau_a}$, the voltage-gain, the gain of the system each $\tau_a$ seconds, in the response of the structure, $i$, times $n_{pp}$. $E_{o}^{\tau_a}$ is the energy into the system each $\tau_a$ seconds.

$$\eta_{sys} = \frac{E_{o}^{\tau_a}}{E_{in}^{\tau_a}} = \frac{E_{o}^{\tau_a}}{E_{in}^{\tau_a}}$$

A general system is shown in Fig. 1. The overall efficiency, $\eta_{sys}$, is the product of efficiencies of the components comprising the system which is calculated as follows. This approach is similar to that of Rasier except that he considered RF efficiency only. The energy into the system is $E_{in}^{\tau_a}$, $E_{in}^{\tau_a}$ = $\eta_{T_{1}}^{\tau_a}$ $\eta_{T_{2}}^{\tau_a}$ $\eta_{T_{3}}^{\tau_a}$ $\eta_{ref_{1}}^{\tau_a}$ $\eta_{ref_{2}}^{\tau_a}$ $\eta_{ref_{3}}^{\tau_a}$ $\eta_{ref_{4}}^{\tau_a}$ $\eta_{ref_{5}}^{\tau_a}$ $\eta_{ref_{6}}^{\tau_a}$, where $\eta_{T}$ is the transmission efficiency, $\eta_{T_{1}}$ is the refrigeration efficiency, $\eta_{ref_{1}}$, $\eta_{ref_{2}}$, $\eta_{ref_{3}}$, $\eta_{ref_{4}}$, $\eta_{ref_{5}}$, $\eta_{ref_{6}}$ are fractions of incident RF energy dissipated in the storage cavity and structure, respectively. $R_{ff}$ are the respective refrigeration factors of the

![Fig. 2. Power dissipated and electric field in a superconducting cavity vs unloaded Q](image)

![Fig. 3. AC to accelerating RF conversion system](image)
In Fig. 4, curves i are plots of \( n \) and \( E \) vs \( a \), and \( E \) vs \( a \) and \( E \) vs \( pp \) for systems using storage cavities with \( Q_0 \) switching.  

1) Pulsed klystron and J-J structure.  
2) RASP and SLAC structure.  
3) RASP and J-J structure.

### References