DEVELOPMENT OF TESLA-TYPE CAVITY AT KEK

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The development of superconducting cavity for high accelerating fields has been continued at KEK on the basis developed for TRISTAN superconducting cavity. Many attempts have been pursued to achieve high field and to understand the phenomena that limit the cavity performance at high field; investigations of how depend on niobium material, surface treatment, heat treatment, surface condition, cavity-shape and cavity-forming. The accelerating fields of more than 25 MV/m have been achieved repeatedly in the several single-cell cavities, even though we did not yet fully understand what had been happened at high field. The present status of those attempts will be reported.

I. INTRODUCTION

The high gradient superconducting cavity is key issue for TESLA (TeV Energy Superconducting Linear Accelerator) project that requires the accelerating field at least 25 MV/m with a Q_0 value of more than $5x10^9$ at 1.3 GHz frequency[1]. The cavity performance to fulfill such high field and high Q_0 may be realized by the good surface condition; less dust and less defect, as well as by the properly designed cavity shape to suppress the multi-pacting. The feasibility of mass production of the multi-cell cavity is also kept in mind when the fabrication method is considered. To investigate possible ways of cavity construction, several materials, cavity-shape and methods such as surface-treatment, heat-treatment and cavity-fabrication, have been tried.

A. Surface property

The surface condition or property might depend on the niobium-materiel itself and the process of cavity construction and preparation:

1. Three RRR materials are used; 100, 200 and 350.
2. Surface treatments such as chemical- (CP) and electro- (EP) polishing were employed as a well-established surface preparation[2]. Tumbling (Tum) was also tried and got promising results. It takes one week for ~50μm polishing. Employ the Tum can omit thick CP/EP, then it may lead to less fabrication cost. Final CP (~20μm) was still employed, then the degassing was the necessary process.
3. Two types of heat treatment were employed. The treatment at 760 - 800 ^{o}C was for degassing of hydrogen that might be absorbed at CP or EP. Whereas, 1400 ^{o}C treatments were tried to improve the niobium property; improving RRR.
4. High pressure water rinsing (HPR) of 85 kg/cm^2 pressure with 13 l/min flow rate are now standard process in addition to the overflow rinsing with ultrasonic agitation (28 kHz) in the hot bath. Megasonic (950kHz) rinsing (MSR) with reflector setting inside the cavity is occasionally used. More effective way such as the agitator itself is setting inside the cavity will be soon ready. Test of megasonic with silicon wafers showed promising result[3].

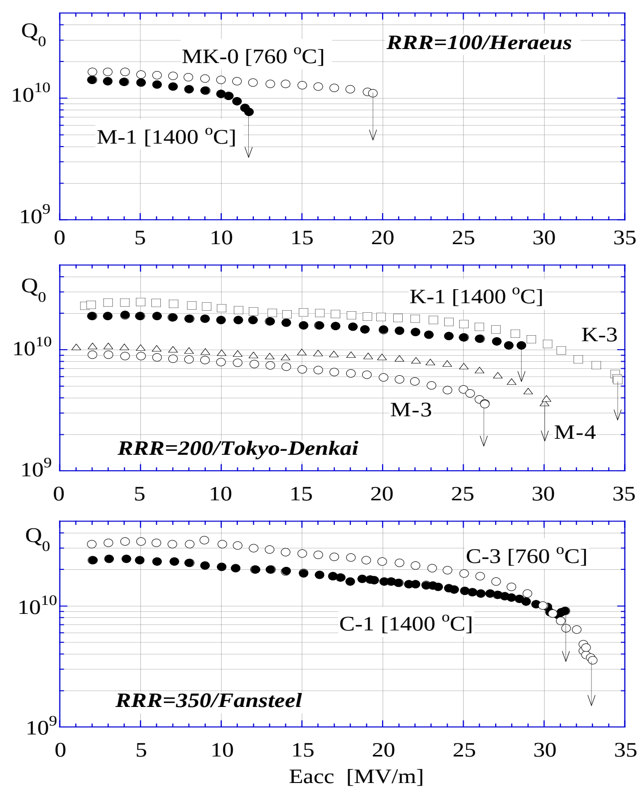

Figure 1. Q_0 vs. Eacc of three RRR cavities.

B. Cavity type

Thirteen single-cell cavities have been fabricated and tested since 1991. Two cavities had been already out of order because of too much polishing but these showed good results; Eacc> 20MV/m. One of the alive 11 cavities was fabricated with wave-guide input coupler. The cold test of this cavity has been done once, but the result was not so good; Eacc<11 MV/m and limited by quench with self-pulsing. It is too early to discuss about this. The results of our test mainly come from these remaining 10 single-cell cavities.

1. Several cavity shapes called spherical type with 4mm and 1mm flat part at equator and elliptic type were fabricated as discussed in ref.[2]. Also asymmetric type has been tried where "asymmetry" means that the spherical and elliptical half cells were welded to make one single cell cavity.
2. Half cells of both of the spherical cavities and elliptical cavities were made by deep drawing method. Spherical half cells of asymmetric cavities were made by spinning. Electron beam weldings (EBW) were employed for half cell and beam tube welding.

No clear dependence of the cavity performances on these shapes was indicated, even though trying several shapes were motivated to see how the cavity shape affect on the multi-pacting. It seems that the present maximum Eacc were mainly governed by the surface property.

C. Experimental apparatus

The cold tests of the cavity have been carried out in the vertical cryostat[2] with movable coaxial input coupler that can be matched to the range of Q_0 from 1×10^{8} (4.2^{o}K) to 5×10^{10} (1.8^{o}K). The cavity vacuum is 5-9 $\times10^{-10}$ at cold.

1. Diagnostic; Occasionally the temperature mapping(684 carbon resisters) and X-ray (8 PIN diode) monitor were equipped. With these signals and the electron yield measured at a monitor port can provide convinced field-emission signal at the steady state. While the transient phenomena such as quench can be observed by rf-signals; transmitted and reflected signals.
2. Residual magnetic field; The measured field at room temperature in the cryostat is ~15mG. However, if the T-mapping is equipped, extra field might be introduced as indicated in the Q_0 degradation of factor 2-3; shown in figure 1(M3 and M4).
3. Removing the ceramic at input coupler; The fatal Q-degradation previously reported as Japanese Q-disease was completely disappeared. This phenomenon didn't relate to the surface properties, even though it might be triggered by the break down at the cavity. The data taken after this will be used for discussion.

II. RESULT AND DISCUSSION

The well prepared cavities of several types show the good performances as shown in fig.1 as irrelevant to the shapes and the fabrication methods. It seems that the surface properties are the main issues to determine the performance at least at presently attained Eacc region; 25<Eacc<35 MV/m.

A. Dependence on the RRR and on Heat treatment

The results of the 200 and 350 RRR attained the Eacc more than 25 MV/m with high Q_0. In the fig.1, the black circles show 1400 ^{o}C annealed cavities. The RRR indicated are the initial value of each cavity. The degassing heat treatments taken after CP or EP were enough to attain the high Eacc as indicated by the white data points. All 1400 ^{o}C annealed cavities show relatively low Q_0 which means the higher residual resistance (Rres) compared to non annealed cavities, even though the sample test of the annealing showed the RRR improving. The two non annealing data of the 200 RRR as indicated by M3 and M4 show also relatively low Q_0, because of extra B-field induced by the T-mapping and not because of less poor surface properties. The two sets of Rres of annealing and non annealing show the RRR dependence consistent with the empirical theory; Rres is proportional to 1/sqrt(RRR) with 20% larger coefficient for annealing set. If we simply suppose that the 1400 ^{o}C annealings improve the RRR, our results are contradicted with this picture. We didn't fully understand these situations, but it can be said that 1400 ^{o}C annealing is not necessarily treatment for attaining the present Eacc range.

The cavities of 100 RRR didn't reach 25 MV/m yet. However one of these (M1) cavity was the first cavity fabricated at MHI and we recognized some imperfect welding part. The other (MK0) is almost attain 20 MV/m. It is not conclusive whether the RRR of 100 is insufficient for attaining 25 MV/m or not.

There would be another question whether the RRR value is good measure for expecting good cavity performance. If we consider the facts that the three RRR niobium-sheet were supplied from three different companies and the 20% deterioration of Rres of the annealed cavities, we can't deny other properties that decide the cavity performance beside the RRR.

B. Dependence on the polishing thickness

Figure 2 shows the correlation between the accumulated polishing thickness and maximum Eacc for several cavity tests. We should point out that three data points that exhibit high Eacc (K2:elp, K4:asy) though the polishing thicknesses are less than 60 µm. These cavities were treated with Tum (~50µm), CP/EP(10µm), 800 ^{o}C degassing, MSR and HPR. Before the degassing both cavities showed Q-disease where only MSR and HPR were applied after CP/EP. If we simply observe the figure 2, the peak is around 300 µm; if we trace one particular cavity, at more than 300 µm polishing no improvement or rather degrade the cavity performance can be observed. It should be pointed out here that the horizontal axis represents also different time for different cavities and several efforts intending to improve the cavity performance have been done in these periods; figure 2 shows the history of our tests after removing the ceramic. The cavities attained Eacc below 20 MV/m are already discussed before; expressed as Q-disease, RRR=100 and with W.G. coupler.

Figure 2 may indicate the possibility that the smaller polishing (~100µm) will be enough for attaining high field; Eacc>25MV/m.

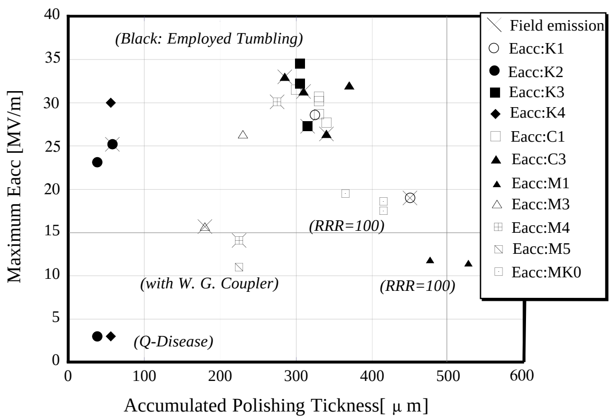

Figure 2. Polishing thickness vs. Eacc. Summary of our cavity cold tests.

C. Decay at maximum Eacc

The observed decay times (τ) of the cavity field at maximum Eacc are ~200 µsec where τ is defined by $\tau_{1/2}$ / ln2. At a glance the decays were almost exponential though we didn't check it precisely. Figure 3 shows the field dependence of τ of several cavities; 16 cold tests of 8 cavities. At high field (>20MV/m) it seems that τ depends on Eacc in a simple way. This behavior may indicate the fact that the quench at maximum Eacc have happened at some limited region of the cavity as explained below. The energy deposit (q) at the surface induce the temperature rise (ΔT) and the quench will be initiated. Two type sources of the q can be considered. The first is ohmic loss given as the product of the defect/dust area (S), current (i) and the extra resistance (ΔR); $q = S\, i^2\, \Delta R$. The second is the deposit by electron irradiation. In this case q, irradiated position and size(S) may be function of Eacc. Assume that whatever the types of q, the τ is mainly determined by the energy deposit at quench-area as given by $q_n = S_n\, i^2\, R_n$ where S_n is area and R_n is resistance of normal state. The S_n may be function of q, S and the thermal quantities of the cavity such as specific heat and thermal conductivity. In the 1st case the q_n is the function of i, R_n and thermal quantities. The position of ohmic loss must be limited to some region to reproduce simple Eacc dependence; possibly at equator. In the 2nd case simple Eacc dependence may be natural consequence once the emitter position is limited to some region; possibly at iris. The data are classified to four categories as strong-, weak-, no X-ray detected at quench and not clear data due to lack of monitor (+). The reasons of these are not understand yet. Same cavity showed different X-ray behavior even though same treatments have been applied. Two types possibilities can show similar Eacc dependence if the position of S_n is near the equator and if they have similar q. Recall that the q/S almost define ΔT, then S is determined if q is given. The nature of quench may indicate that the equator and iris are suspicious place for limiting our maximum Eacc; welding part or dust.

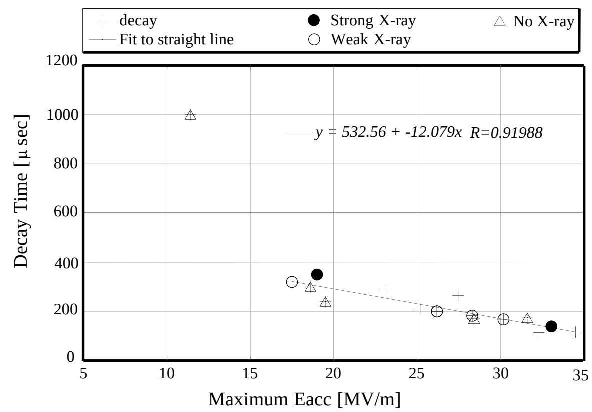

Figure 3. Field dependence of decay time.

III. CONCLUSION

To attain the high field the RRR of 200 is enough. Not so much polishing may be required with our recent treatment. The cavities seem to be limited by thermal quench caused by the defect/dust at equator or iris. The effort to make seamless cavity by explosion is just started for intending to reduce the cost. Eliminating the suspicious welding part may also break through the present limit. The investigations of niobium properties by the magnetization method are now progressing and may reveal important aspects of the surface properties including the welding part.

IV. REFERENCES

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