# EXPERIMENTAL FORMULA OF THE ON-SET LEVEL OF TWO-POINT MULTIPACTING OVER THE RF FREQUENCY RANGE 500MHZ TO 1300 MHZ

K.Saito†, KEK Accelerator Lab, 1-1 Oho Tsukuba-shi, Ibaraki-ken, Japan

*Abstract*

Multipacting is reconsidered for the niobium sc cavities with clean surface treated by high pressure water rinsing (HPR). Since 1992, we have reported the existence of two-point multipacting in niobium cavities even with such a clean surface. So far, we fabricated many cavities at several RF frequencies (508, 600, 1300 MHz) and several βs (1.0. 0.89, 0.64, 0.45). Multipacting was observed in all of the cavities. In this paper, we present an experimental formula for two-point multipacting over the frequency range and the βs. This formula is very consistent with the simulation result by R. Prodi et al..

## 1 INTRODUCTION

In 1984, W.Weigarten in CERN pointed out the existence of two-point multipacting in spherical superconducting niobium cavities of 500 or 350 MHz [1]. After that, rinsing technology in cavity preparation has been much improved as seen in high pressure water rinsing (HPR), and it looks to be forgotten in a tacit expectation for such the upgraded clean surface. However, recently this issue has become clearly in KEK after eliminating field emission by HPR.

In TRISTAN sc 508 MHz cavities, one weak barrier was always observed around accelerating field Eacc = 7 MV/m in every cavity [2]. This barrier is considered as two-point mutipacting from CERN results. We have thought that the barrier might be related to the performance degradation in the TRISTAN horizontal final cavity assembly: achievable gradient was lowered to 7MV/m from 10 MV/m in vertical test, Qo value was also dropped to $1.7\times10^9$ in average from $2.8\times10^9$ (at 5 MV/m) and scattered. Since 1990, we have continued R&D at L-band (1300MHz) for future sc applications. From the TRISTAN experience, we were very careful about multipacting in this R&D. In vertical test, a considerably strong barrier followed by x-ray appeared around Eacc =16 - 18 MV/m in almost every cavity with 1300MHz and beta=1. This barrier is also consistent with two-point multipacting expected from CERN results. We have not yet identified directly the barrier is a multipacting by thermometry or x-ray photo spectroscopy, however, we have been very sure the existence of two-point multipacting even in clean surface

Today, fortunately we have a chance to work at other different frequencies: 508, 600, 972, 1300 MHz or many kind of β(= v/c) : 1.0, 0.89, 0.725, 0.64, 0.45 in the KEK/JAERI joint project for sc proton LNAC. We observed corresponded barriers in all of these cavities. In this paper, we will present a typical phenomenon of the barrier in our L-band cavity by x-ray measurement outside of cryostat during taking excitation curve measurement. Then, experimental formulas for the two-point and one-point multipacting are presented for the wide frequency ranges and βs.

## 2 MULTIPACTING BARRIER

### *2.1 Behaviour in the Qo-Eacc Excitation Curve measurements*

Multipacting seems to be more serious in KEK than other laboratories, where it passes easily by light RF processing so that one cannot notice the existence. The reason is not yet clear but electropolishig might be a cause. Sulphur precipitates during electropolishing due to resolution of sulphuric acid at cathode [3]. Multipacting barrier is observed with a probability of 95% in KEK.

Figure 1 shows a typical x-ray observation in our L-band niobium sc cavity with β=1 during taking an excitation

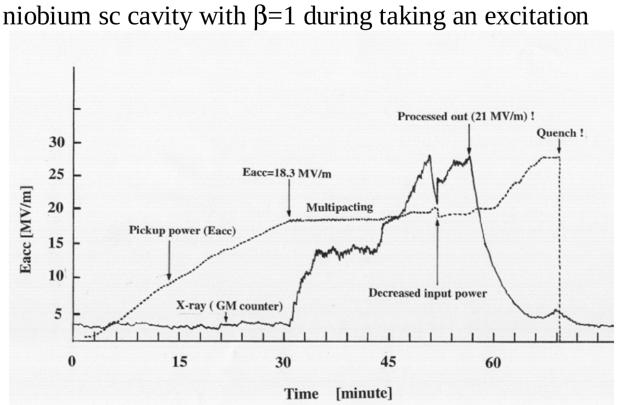


Figure 1: Multipacting during excitation cure

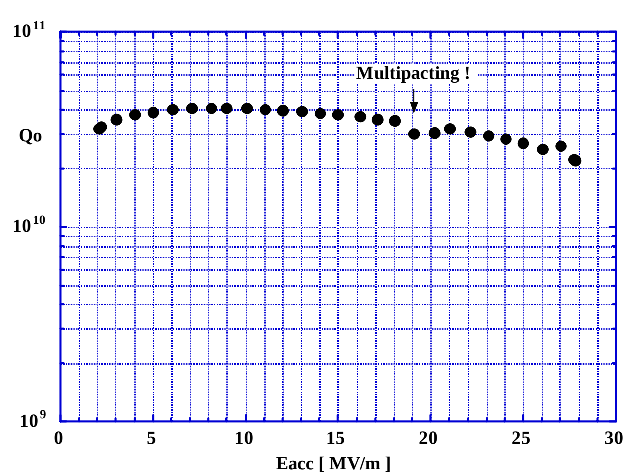


Figure 2: Multipacting seen in excitation cure

†ksaito@post.kek.jp

curve. X-ray is measured with G-M counter on the top flange of the vertical cryostat. This way does not give any information about electron hitting location on the inner surface, but is very convenient to see the x-ray occurrence. The x-ray detection sensitivity is as high as photodiode put on cavity wall in liquid temperature because the resultant x-ray shower amplified by multi-scattering. One can see x-ray starting abruptly from 18.3 MV/m in Fig.1. Accompanying x-rays, RF processing was continued slowly up to 21 MV/m, then x-ray disappeared suddenly and gradient was quickly increased to the field limit. It takes about 30 minutes to process out the barrier. The excitation curve after RF processing is presented in Fig. 2. An obvious Qo-dropping appeared in the curve but it is a special case. After RF processing, Qo value is usually dropped over all of the field range as seen in Fig. 3 (■) but it is recovered after warmed up just to the super-conducting critical temperature (Tc = 9.25K) of niobium as seen in Fig.3 (○). The degradation is considered as flux trapping. The flux trapping effect is small in niobium bulk cavities but it badly appears in Nb/Cu clad cavities as seen in Fig.3. Once being RF processed out, the processed effect is memorized in warming the cavity up to around 200K but it is gone by warming up to higher temperature.

This multipavting barrier could limit the gradient in the horizontal final cavity assembly. By recent study, nitrogen gas exposure after the vertical test brings various degradation depending on exposure process [4]. In the worst case, the exposure makes even one-point multipacting. The performance degradation in the TRISTAN sc cavity final assembly can be explained by the enhanced multipacting by nitrogen exposure.

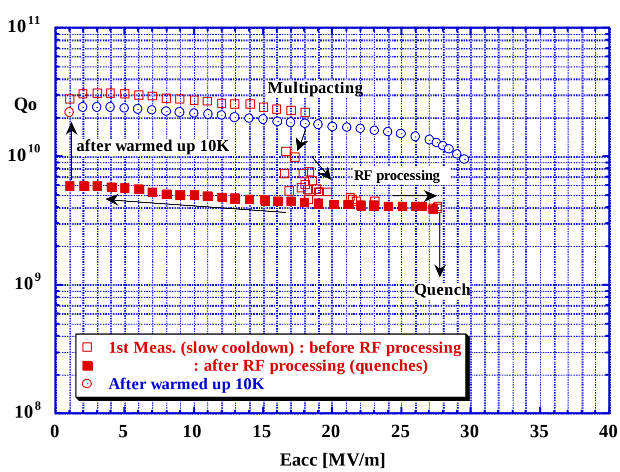


Figure 3. Flux trapping in RF processing of multipacting barrier in Nb/Cu clad cavity

## *2.2 DESY Temperature Mapping Measurements*

We have no data but L.Lilje in DESY has been to measure the temperature mapping with electropolished 1300 MHz mono-cell cavities [5]. He observed a nice heating spots due to two point multipacting. Fig.4 is his measurement result. Two localized heating spots cross the equator are observed clearly. He confirmed the spots moved during the processing.

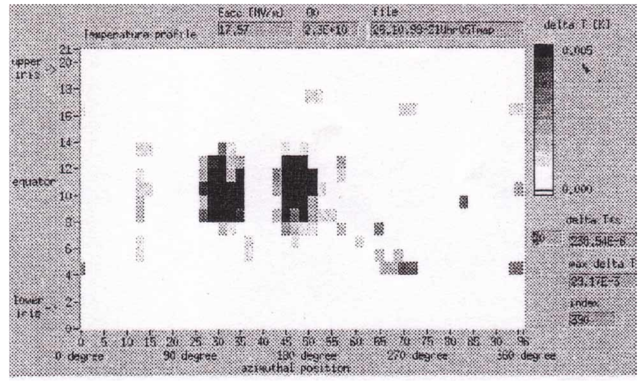


Figure 4: Temperature mapping at the processing level (Each=17.5 MV/m) taken in DESY . from Ref. [5].

## 3 EXPERIMENTAL FORMULA WITH TWO-POINT MULTIPACTING

Multipacting happens in synchronization between electron motion and RF frequency on cavity inner surface. The occurrence is foreseen by the synchronization and a classical low of thumb: cyclotron frequency. The following relationships are expected for one point n-th order multipacting and two-point n-th order multipacting:

$$H_{RF}\ (\text{1point n-th}) \sim f_{RF}/n \qquad (1),$$

$$H_{RF}\ (\text{2point n-th}) \sim f_{RF}/(2n-1) \qquad (2).$$

Here, n is a positive integer larger than 1. $H_{RF}$ (1point n-th) or $H_{RF}$ (2point n-th) is the occurrence field level. So far many multipacting simulations have been done individually with different frequency or different cavity shape, however, they are too complicated and give no simple view. One purpose of this pare is to find out a convenient experimental formula over a wide frequency rang or betas.

### *3.1 Two point multipacting*

X-ray observation is summarized in Fig.5 with our cavities: 508 MHz β=1 TRISTAN cavity, 600 MHz β=0.83 JAERI cavity, 1300 MHz β=1 TESLA type cavity, 1300 MHz β=0.45 cavity. Here, we used surface RF magnetic peak field Hp instead of $H_{RF}$. Hp is calculated by the ratio Hp/Eacc, which is obtained by a cavity design code, e.g. SUPERFISH. If these x-ray observations are due to multipacting, one will expect the same x-ray on-set level for every frequency, Hp being presented with normalized field (Hp/$f_{RF}$) with the RF frequency: $f_{RF}$. Fig 4 shows a very nice agreement with the on-set level with every cavity. It has to be emphasized that the agreement is true with different βs among 1.0 – 0.45. From the fitting, one can deduce a following experimental formula:

$$\text{Hp [Gauss]} / f_{RF}\text{[MHz]} = 0.60/(2n-1) \qquad (3).$$

On the fitted on-set level, one cannot assign it to be two-point n-th multipacting. However, putting n=1 and $f_{RF}$ = 500 or 350 MHz into the formula, then comparing with CERN two point multipacting assignment which were nicely identified by thermometry and x-ray photo spectroscopy, the formula give a good agreement. Another reason considered the eqation (3), as two point multipacting is that the formula has very good agreement with the two point multipacting simulation by Dr. R.Palodi at INFN Geniva simulated for SNS btea-0.61 and 083 800 MHz cavities [6]:

$$Hp/f = 0.56/(2n-1) \qquad (4).$$

Equations (1) and (2) are for perfect synchronized electron motion with RF frequency, then the resultant occurrence appears at discrete levels. However, the resonance condition will be changed gradually by electron bombarding itself. The bombarding site will shift during the motion. Thus real multipacting is observed over a field range. On the other hand, instead of the perfect resonated electrons there will be multipacting electrons losed the synchronization during their motions. These escaped electrons will make a rather strong x-ray background with increasing field gradient. This effect appears in high field range with a field emission like Qo-slope in excitation cures. Generally speaking, with a rather less contaminated surface, the surface also gets clean by electron bombarding so that the secondary emission yield will be smaller and finally the multipacting disappears.

### *3.2 One point multipacting*

With one point multipacting, it is sometimes observed in very contaminated L-band cavities in KEK. It has an x-ray on-set level around 9 MV/m. This level is no matching with the formula (3): two-point multipacting. Assuming it as one point multipacting with n=1, we can deduce a experimental formula corresponding to the equation (1) as following:

$$Hp\ [Gauss]/f_{RF}\ [MHz] = 0.3/n \qquad (5).$$

On the other hand, Parodi's simulation obtains an equation for one point multipacting [6]:

$$Hp\ [Gauss]/f_{RF}\ [MHz] = 0.28/n \qquad (6).$$

Since one point multipacting occurs at such a low field in rather contaminated surface, it accompanies a field emission like Qo-slope. Therefore it is confusable with field emission.

## 4 CONCLUSION

So far we has reported the existence of multipacting with clean cavities by our circumstantial evidences. However, the phenomenon is confirmed in a wide RF frequency range : 500 - 1300 MHz and in various betas : 1.0 - 0.45. The on-set level of the phenomenon is well scaled by the frequency. The experimental formulas with multipacting given here are very consistent with simulation results.

## 5 REFERENCES

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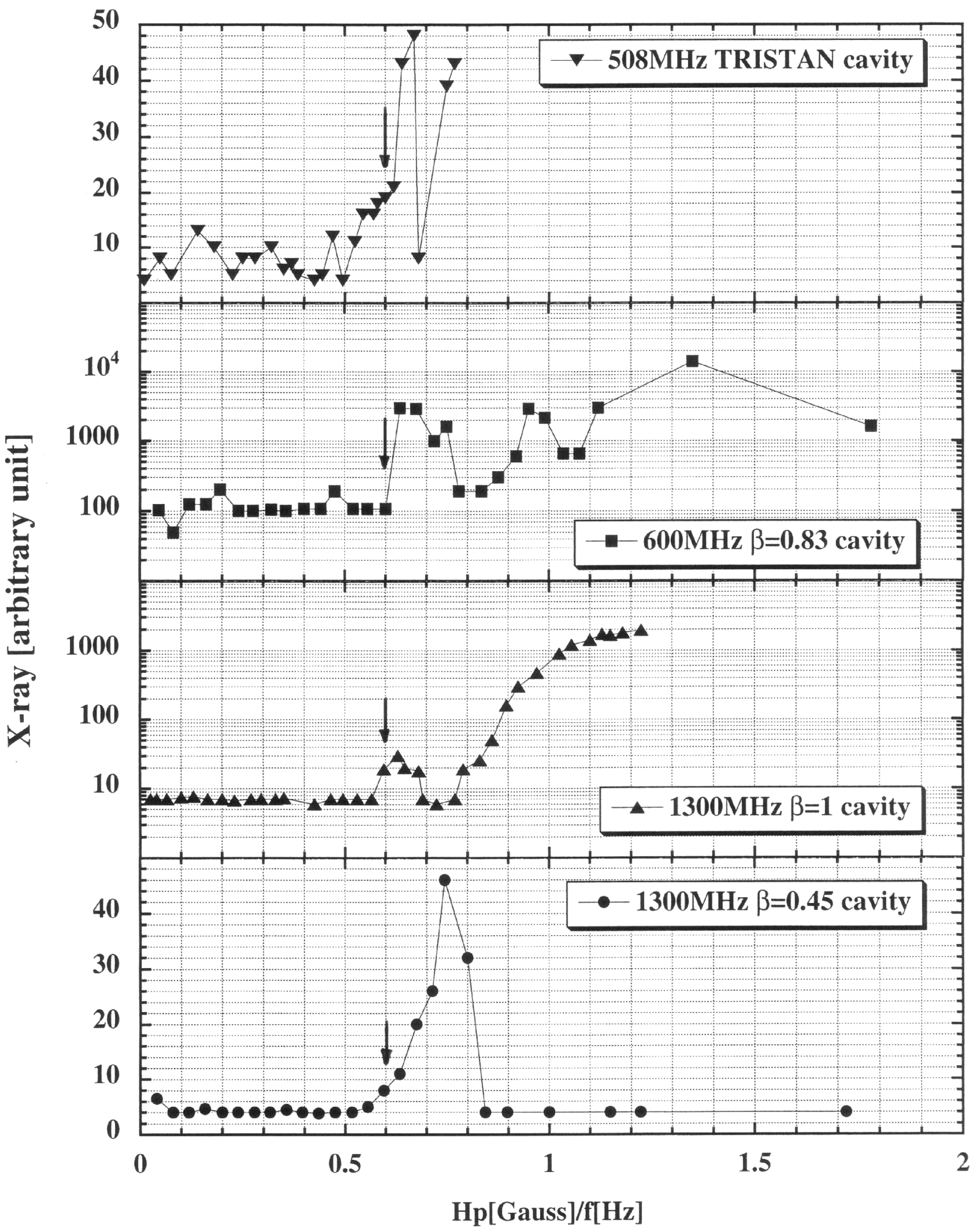


Figure 5 : Multipacting barrier presented field scaled by RF frequency ($Hp/f_{RF}$)