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学 位 論 文 題 目	Study on Multipacting Phenomena of Low Temperature Cavity with respect to Condensed Gasses on its Surface
論 文 審 査 委 員	主　査　教授　黒川　眞一 教授　春日　俊夫 教授　小林　正典 教授　細山　謙二 助教授　古屋　貴章 教授　松沢　秀典（山梨大学） 教授　光延　信二（高エネルギー加速器研究機構）

Abstract

Multipacting is a common phenomenon of spontaneous electron loading in resonant structures, either normal or super conducting. These electrons interact with the rf field inside the resonant structure and thus cause an abrupt and huge loss of rf field. As a result, multipacting appears as a performance limiting phenomenon of resonant structures, e.g., cavity and waveguide.

In the case of superconducting cavity, due to cool down to cryogenic temperature from room temperature, residual gas molecules adsorb on the inner surface of cavities and couplers. A common speculation is that these adsorbed molecules enhance the multipacting. In the research and development of superconducting Crab cavity for KEKB electron-positron collider, a severe multipacting is observed during the first time rf excitation after the cool down at 4.2K from room temperature. After processing the multipacting, if the cavity is kept at 4.2K, this multipacting is never observed during the following rf excitation. Also, in the case of KEKB superconducting accelerating cavities, multipacting is observed at and around the input coupler during the long time operation of KEKB. This observance of multipacting may be explained as that adsorption of residual gas molecules may cause this multipacting. Being inspired by these experimental hints, we have devoted our effort to understand the multipacting with respect to the adsorbed gas molecules.

Our study is different from the present trend of multipacting research – simulation of multipacting and study on secondary yield. In our study, we have focused our concentration in the origin of multipacting. What molecules are responsible in multipacting? Is there any difference between monolayer and multilayer of adsorbed molecules in multipacting? In our study, we have tried to find out this kind of fundamental answers in an attempt to trace out the seed of multipacting.

At first, we have designed and built up a dedicated experimental setup to learn the adsorption and desorption of residual gas molecules on cryo-cooled surface. Most exciting part of our experimental setup is to

develop a Gas Flow Control System, by which we have efficiently controlled the number of molecules admitted into the vacuum chamber. This has enabled us to study the adsorption and desorption of gas molecules with respect to monolayer and multilayer. As the experimental surface on which adsorption and desorption has been studied, we have designed a cylindrical vacuum chamber. This vacuum chamber has been fabricated from the thick cylindrical pipe of oxygen free high conductivity (OFHC) copper so that the temperature distribution along the length of vacuum chamber becomes negligible. Since the most dominant residual gas molecule in ultra high vacuum is H_2, we have extensively studied the adsorption and desorption of H_2. We have found that H_2 has a saturated pressure of the order of 10^{-4} Pa at 4.2K. Desoprtion of H_2 from monolayer as a function of temperature can be characterized by a broad peak at 14K. On the contrary, desorption of H_2 from multilayer occurs very sharply at around 5.6K.

Experience of the adsorption desorption experiment has been carried in the experiment of multipacting with respect to adsorbed gas molecules. For this study, we have designed and built up a coaxial type resonant cavity of resonant frequency is 1.5 GHz. Mode of excitation has been so chosen that different cutting parts, for example, vacuum opening at inner conductor, have been adopted at the places where rf surface current is zero. This mode selection has enabled us to build up a coaxial cavity of rather high unloaded Q from OFHC copper. Another important feature of our design is that the inner and outer conductor can be easily separated from each other. This feature provides different options to study the multipacting. For example, besides the very easy access to the multipacting site, we can change the surface condition at the probable multipacting site. We have also designed and built up the unit coupling input probe, different monitor probes and the cryostat top flange.

To study the multipacting, we have used three parameters: i) vacuum pressure, particularly, for multipacting at room temperature, ii) current due to multipacting electrons, and iii) reflected and transmitted signals from the cavity. In the study of room temperature multipacting, We have found that after processing of the multipacting observed below the peak electric field of 0.28 MV/m, these multipacting incidents do not occur during the subsequent rf excitations, if the cavity is not exposed to ambient air.

Multipacting above the peak electric field of 0.28 MV/m occurs during every rf excitation, even if the cavity is not exposed to ambient air. Room temperature multipacting observed above 0.3 MV/m has been found not to become processed without baking at 100^0C. This effect of baking hints that water molecule may cause or enhance multipacting. In contrast to room temperature, multipacting levels at 4.2K are few and soft. Once processed, multipacting does not occur if the cavity is kept at 4.2K. We have studied the multipacting at 4.2K with respect to different amount of adsorption of H_2 – from saturated H_2 surface to partial monolayer of H_2. Our experiment has revealed that adsorbed H_2 does not act as the seed of multipacting, rather suppresses the multipacting. We have also studied the effect of other dominant residual gas molecules CO. We have found that CO too does not act as the seed of multipacting. Also, the development of multipacting in micro-second level has been studied.

論文の審査結果の要旨

Mashiur Rahman 氏の論文は、ヘリウム温度に冷却された金属表面に凝縮した水素や一酸化炭素などがマルチパクチングにどのような影響を及ぼすかについての研究を主題とするものである。

近年加速器に多用されるようになった超伝導空洞において、運転を続けるうちに、次第にブレークダウンの頻度が大きくなる現象が観測されてきた。この原因は、運転時間が長くなるにつれて、空洞内表面に凝縮する水素が多くなり、この凝縮水素がマルチパクチングを起こしやすくするためであると思われてきた。Rahman 氏の研究は、空洞内面に、水素と一酸化炭素を分子の層数を制御しながら凝縮させ、凝縮した分子の層数とマルチパクチングの頻度を実験的に調べることにより、ヘリウム温度でのマルチパクチングと凝縮分子の関係を明らかにしたものである。この研究は、超伝導空洞を高電場を達成しつつ安定に運転するために、重要な知見を与えるものである。特に高エネルギー加速器研究機構の B ファクトリーの性能向上の有効な手段であると考えられているクラブ空洞は、ファンダメンタル・モードを取り出すための同軸構造を持っており、この部分におけるマルチパクチングを回避することは、クラブ空洞実現における最重要課題である。Rahman 氏の研究はこの問題に直接取り組むものである。

Rahman 氏は、まず、同軸型試験空洞に、微量のガスを、制御しながら導入する装置を開発し、低温に冷却された金属（銅）表面に凝縮する分子の層数を制御することに成功した。この結果、水素分子が１層のみ金属表面に凝縮したときと、２層にわたって凝縮したとき、第１層が金属から解離するエネルギーが、第２層目が第１層目から解離するときのエネルギーより大きいことを明確に示すことができた。このことは、Rahman 氏が開発した装置が凝縮層数を制御できることを明らかに示すものである。

次いで、Rahman 氏は、ヘリウム温度に冷却された銅表面に水素分子を凝縮させ、高周波電磁場を印可することにより、マルチパクチングがどのように発生するかの実験を行い、(1)凝縮水素分子が金属表面を完全に覆ったときには、凝縮した層数にかかわらず、常温のときに頻発したマルチパクチングが完全に制御されること、(2)凝縮分子が１層のみであり、かつ表面を完全に覆い尽くさないときには、マルチパクチングが発生すること、を示した。この実験結果は、凝縮した分子がマルチパクチングを制御することを明確に示しており、これまでの常識をくつがえすものである。

Rahman 氏の研究成果は、今後の研究の端緒となる重要なものであり、審査員全員が一致して、Rahman 氏の論文は博士論文に値すると判定した。