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学位論文題目	Bunch Deformation of a Multi-Bunched Beam in Electron Storage Rings
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In an electron storage ring, electrons form a cluster called a bunch. The distribution of electrons becomes a Gaussian shape if we neglect the interaction between the electrons and the vacuum vessels. With the increase of the bunch current, the interaction becomes strong and acts as an external force which is called a wakefield. When an electron storage ring is operated in a single bunch mode, the current dependence of the bunch length is explained by the potential well distortion due to the wakefield and the microwave instabilities. These theories were successfully applied to the bunch lengthening in the TRISTAN Accumulation Ring (AR) at KEK, National Laboratory for High Energy Physics. On the other hand, a remarkable bunch deformation was observed when several bunches were stored in the AR. In some cases several bunches have different stationary longitudinal distributions, exhibiting two peaks or like a trapezoid. The main purpose of the present study is to find out the sources and the mechanism of the anomalous bunch shape deformation, which cannot be explained by the conventional bunch lengthening theory.

For this purpose, first of all, we carefully measured the bunch shape in a two-bunch operation mode with a streak camera. The two bunches were injected into the opposite sides of the ring. We found that the anomalous deformation of the longitudinal bunch shape occurs when two bunches have different currents. We call, hereafter, the smaller current bunch a weak bunch and the larger current bunch a strong bunch. We found that the length of the weak bunch becomes quite longer than that of the strong bunch. This observation, however, did not agree to the standard bunch lengthening theory with which the bunch is lengthened with the increase of the bunch current. The fact that the deformation of each bunch was stable for long time over the synchrotron oscillation period and was observed even at the bunch spacing of a half of the ring circumference clearly suggests that the deformation is caused by the potential well distortion due to high-Q components in the ring. In the AR, the higher order modes (HOMs) of the accelerating cavities are the most probable suspects.

The next step was to determine the frequency and the strength of the wakefield which is responsible for the anomalous bunch deformation. A new idea, called a test bunch measurement, was proposed for this purpose. The basics of the method is as follows. We inject a strong bunch which induces a wakefield and at the same time inject a sufficiently weak bunch whose wakefield is negligible. Because the shape of the weak bunch is deformed or shifted due to the wakefield induced by the strong bunch, we can estimate the mode frequency by changing the distance between the two bunches. We discussed the effectiveness of the test bunch measurement with the numerical calculations, and decided to measure the peak position of the test bunch.

To find the best way for detecting the peak position of the test bunch, we tested a photon counting method, a beam position monitor and a fast photodiode. Each method are carefully evaluated and the photodiode was most appropriate for our purpose. Because it is very time-consuming to measure all buckets in the AR, we measured only successive 21 buckets in nine parts in the ring. Among the measured peak positions of the test bunch, there was some offset component. We take account of the transient beam loading effect on the acceleration mode of cavities and concluded the magnitude of the offset agrees well to the calculation.

The wakefields measured with the test bunch method has three frequency components. We also observed the beam induced signal with the pickup at the end-plate of the RF cavity and concluded that one component corresponds to the short range wakefields that lasts until about 100 buckets after the main bunch. The component has less contribution to the deformation. The other two frequency components induce the long range wakefields which may affect the bunch shape in the two bunch operation. The candidates of the source of the deformation are TM020C, TM030 and TM022 modes. It is impossible to distinguish the first two modes with the test bunch method.

At last, we estimate the strength of the wakefields with three methods. The first one is the calculation of the HOM impedance with the computer code SUPERFISH. The second one is to estimate the wakefield from the bunch shape deformation under the two bunch mode. Our model is based on the assumption that the accelerating RF field and several long range wakefield due to the HOM determines the bunch shape. We applied our model to the Haissinski formula which gives the general bunch shape under any wakefields. We fit the measured bunch shape with the formula and estimated the strength of the HOM. The last one is the Fourier transform of the peak position data at the test bunch measurement. We obtained not only the strength of the two long-range wakefields but also the phase of each mode. We found that the estimated field strength in three approach are within a reasonable agreement taking account of the fact that eight cavities are installed in the AR and the resonant frequency and shunt impedance of HOMs are different among cavities.

We have also made preliminary bunch-shape measurements in four-bunch and eight-bunch operations and observed anomalous bunch deformation. It is a future work to study these cases in detail. The APS cavities in the AR will be temporarily replaced with another type of cavities for a test of large-current storage simulating the KEKB operation. It would be very interesting to measure the bunch-shape deformation after removing the APS cavities and minimizing long-range HOM fields.

論文の審査結果の要旨

帯名崇君の博士論文は、電子貯蔵リングに複数個のバンチが貯蔵されているときに観測されるバンチ長の異常な振舞いについて、精密、詳細な測定を行い、かつその理論的解釈を試みたものである。

貯蔵リングにおけるバンチ形状、特にその長さを適切に制御することは、放射光源その他に応用するうえで極めて重要である。リングに単バンチのみが貯蔵されている場合のバンチ長は電流とともに増大し、その様子はHaissinnski理論で良く説明されてきた。しかしバンチが複数個の場合、個々のバンチ長の関係は複雑な様相を呈することが知られており、それは単バンチの場合と同様にウェーク場によるものであるが、それを適切に説明するための理論的検討はほとんどない。

帯名君の研究はこの点を究明するためにトリスタン入射蓄積リングを使って行われたものである。まず問題を単純化するために、貯蔵バンチ数を２とし、リングの１８０°の位置に置いた。つぎに２個のバンチ電流が揃っている場合、そうでない場合についての個々のバンチ長を詳細に測定した。その結果、前者の場合ではバンチ長の電流依存性は単バンチ運転で予想されるものとほぼ合致したが、後者の場合は、電流の小さいバンチの方がむしろかなり長くなるという奇妙な現象を発見した。

そこで帯名君はウェーク場をより精密に調べるべく、極めて小電流のモニターバンチを先頭バンチの後方のいろいろな場所(バケット)に入射し、その位相変位の観測をおこなった。その結果をフーリエ分解したところ、加速空洞で同時に観測される高調波モードと一致することが判明した。この傾向はＳＵＰＥＲＦＩＳＨコードによる空洞高調波モードおよびそのインピーダンスの解析でも裏付けられた。そのうえ問題となる高調波モードの周波数のバンチ周回周波数に対する比が偶数か奇数かによるリング１８０°位置でのバンチが感じる総合的な場の性質を考察した。そこで奇数モードがバンチ長に大きい影響を持つことを発見した。

このようにウェーク場の情報をHaissinnskiの公式に代入し、バンチ長を改めて計算すると、はじめに述べたバンチ長の異常な振舞いがかなり精度良く再現することができた。この結果は世界初といえるものであり、これによって、多バンチ貯蔵時においても古典的なHaissinnski公式が適用可能であるという重要な知見が得られた。この結果に到達したことはまた、バンチ長を数種類におよぶ独立な方法で精密観測し、また貯蔵電流値により微妙にずれる高調波周波数を丹念に追及したことにもとづくものであり、帯名君が卓抜した実験技術の持ち主であることを証明している。