On the Electro-Gravitational Induction Predicted by Beam Instability in Charged Particle Storage Rings

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Abstract: Changes in beam position within charged particle accelerator storage rings have been observed due to changes in gravity (Δg) caused by the moon and sun. The terrestrial tidal model has been used to explain this type of beam instability. Further analysis reveals that these instabilities arise from changes in the electron beam energy, rather than from movements of the accelerator components due to terrestrial tidal forces. We suggest a potential model to better explain this type of instability. Consider a charged particle beam ring rotating with the earth, perpendicular to the moon's line of gravity. We induce an electromotive force along the ring, referred to as electro-gravitational induction (EGI). The circular motion of the charged particles causes the accumulation of the EGI in the storage ring, turn by turn. We used existing data from storage ring beam signals to estimate the maximum value of the gravity coefficient of the induced electromotive force.

One Sentence Summary: We have postulated the existence of electro-gravitational induction (EGI) in a particle storage ring.

Introduction

In particle accelerator storage rings, some changes to the beam position have been observed via beam position monitors (BPMs), detected as changes in the amplitude of the closed orbit distortion (COD) in a 12-h cycle of the beam. The location of the beam has been found to change due to the gravitational pull of the moon and sun; i.e., due to the effects of gravitational forces on the orbit of the charged particles in the storage ring. Current research on this topic has made use of a terrestrial tidal model *(1-3)*. The terrestrial tidal force changes the ground surface and therefore all components of the storage ring, including the BPMs, bending magnets, etc., that are fitted to the ground. Therefore, the movement of the ground changes the beam orbit, which will cause the beam energy to change. We note that there are two kinds group of BPMs alternately around the storage ring: one group is in the dispersive region and measures the beam position change due to an energy change and the other is in the non-dispersive region and measures position change arising from other sources, i.e., not energy change. For example, the SPring-8 ring has 88 BPMs in the dispersive region and 200 BPMs in the non-dispersive region. The BPM data *(1-3)* show that the COD exhibits changes in the dispersive region, indicating that the COD changes due to the beam energy change; this behavior was attributed to the terrestrial tide. However, the COD is unchanged in the non-dispersive regions *(2)*; this means that the positions of the bending magnets and BPMs are not changing.

Therefore, we suggest that in the dispersive region, the COD change is caused only by the change in beam energy; it does not arise from a change in BPM position due to ground expansion, as predicted by the terrestrial tidal model.

This phenomenon, in which the moon and sun cause an energy change in the charged particle path, includes two significant physical quantities: the intensity change of the gravitational field, and the energy change of the charged particles. We consider whether this phenomenon implies that the gravitational force has a direct effect on the moving charged particles. We discuss the possibility that the gravitational field produces an induced electric field, which changes the energy of the charged particles, and investigate whether this electro-gravitational induction (EGI), i.e., the interplay of the gravitational force and the electro-magnetic induction, can be observed. We also present some results for the coefficient of the EGI.

Model of the Electro-Gravitational Induction

In this section, we present the method used to quantify the EGI.

Let the line perpendicular to the intensity of the gravitational field $\vec{\mathrm{g}}$ be denoted by $\mathrm{d}\vec{\mathbf{l}}$. When $\mathrm{d}\vec{\mathbf{l}}$ moves perpendicular to $\vec{\mathrm{g}}$ with a velocity $\vec{\upsilon}$, it will produce an electromotive force $\overrightarrow{\mathcal{E}_{\mathrm{g}}}$ along the line $\mathrm{d}\vec{\mathbf{l}}$,

$$\overrightarrow{\mathcal{E}_{\mathrm{g}}} = -\xi\,(\vec{\upsilon} \times \vec{\mathrm{g}})\,\mathrm{dl} \tag{1}$$

where ξ is the EGI coefficient. The line integral of (1) is the electromotive force $\mathcal{E}_{\mathrm{g}}$.

Then the net gravity-induced electromotive force after one turn in the accelerator storage ring is,

$$\mathcal{E}_{\mathrm{g}} = \oint_{\mathrm{ring}} -\xi\,(\vec{\upsilon} \times \vec{\mathrm{g}})\mathrm{dl} \tag{2}$$

If a charged particle $\boldsymbol{q}$ with velocity v_p moves in an accelerator storage ring with radius $\mathrm{R}_{\mathrm{ring}}$, within the given time dt, the particle moves around the storage ring $(v_p\,dt/\mathrm{L}_0)$ and so the energy change of the particle will be,

$$\mathrm{dE} = q\,\mathcal{E}_{\mathrm{g}}\,\frac{v_p}{\mathrm{L}_0}\,dt \tag{3}$$

$$\Delta\mathrm{E} = \int q\,\mathcal{E}_{\mathrm{g}}\,\frac{v_p}{\mathrm{L}_0}\,dt \tag{4}$$

For a given storage ring, we have the following expression:

$$\Delta\mathrm{E} \approx \frac{\Delta\mathrm{L}}{\mathrm{L}_0}\cdot\frac{\left(\mathrm{E}_0{}^2 - \mathrm{E}_{00}{}^2\right)}{\mathrm{E}_0} + (\mathrm{E}_0 - \mathrm{E}_{00})\;\mathscr{E} \tag{5}$$

where L_0 is the expected path perimeter, E_{00} is the rest energy of the charged particle, E_0 is the beam energy for the expected central orbit in the storage ring, and ΔL and $\Delta\mathrm{E}$ are the change in the expected path perimeter and the corresponding change in energy, respectively.

To calculate equation (2), we used the following approximation,

$$\mathcal{E}_{\mathrm{g}} = \oint_{\mathrm{ring}} -\xi\,(\vec{\upsilon} \times \vec{\mathrm{g}})\mathrm{dl} \approx$$

$$\int_{-\pi/4}^{\pi/4}\int_{-\pi/4}^{\pi/4}(-\xi)\frac{dg}{dr}\,R_{ring}\,\sin\varphi\sin(\theta_0+\omega t)\,\sin\gamma_1\,R_{ring}\,\sin\gamma_2\,\omega\,R_{earth}\cos\varphi\cos(\theta_0+\omega t)\,d\gamma_1 d\gamma_2 \quad (6)$$

where R_{ring} is the radius of the storage ring, R_{earth} is the radius of the earth, φ is the latitude of the storage ring, ω is the rotational-angular velocity of the earth, r is the distance between the storage ring and the moon or sun, and γ_1, γ_2 are the integrals of the angle variables of the storage ring.

So that equation (2) can be described as,

$$\mathcal{E}_{\mathrm{g}} = (-\xi)\frac{d\vec{\mathbf{g}}}{dr}\cdot\vec{\boldsymbol{S}}_{ring}\cdot V_{ring\times\frac{d\vec{\mathbf{g}}}{dr}} \quad (7)$$

where the charged particle ring C is bounded by an open surface $\vec{\boldsymbol{S}}_{ring}$ with unit normal $\vec{\mathbf{n}}$

and $V_{ring\times\frac{d\vec{\mathbf{g}}}{dr}}$ is the velocity of the surface $\vec{\boldsymbol{S}}_{ring}$ in the direction perpendicular to the gradient $\vec{\mathbf{g}}$.

This means that the EGI would be proportional to the gradient $\vec{\mathbf{g}}$, surface $\vec{\boldsymbol{S}}_{ring}$ and velocity of the surface $\vec{\boldsymbol{S}}_{ring}$ in the direction perpendicular to the gradient $\vec{\mathbf{g}}$.

Discussion

As a preliminary estimation, we disregarded the influence of any factors other than gravity on the beam position and used the maximum change per day in the amplitude of the COD in the calculation of the ξ maximum value, as we did not know what kind of feedback systems were working in the storage ring when the BPM data were measured or what the primary influence on the beam orbit was. Table 1 shows the relative expected path perimeter and the corresponding change in energy for several major storage rings *(1-3)*.

Table 1. Parameters for different storage rings

	NL	L_0(m)	E_0(GeV)	ΔL_{max}	ξ (maximum) $\left(10^{-2}\ \mathrm{stat}coul^{-1}\cdot m^{-1}\cdot\mathrm{kg}\cdot\mathrm{s}\right)$
LEP[1]	46	26658.9	91	0.1mm	3.76
SPring8[2]	34.9	1435.9	8	56μm	2.09
APS[3]	41.7	1105	7	40μm	3.78

NL: Northern latitude; L_0: Expected path perimeter; E_0: Beam energy in GeV; ΔL: measured COD changes; ΔL_{max} : maximum COD change per day; ξ: calculation of the EGI coefficient in $\mathrm{stat}coul^{-1}\cdot m^{-1}\cdot\mathrm{kg}\cdot\mathrm{s}$.

The EGI coefficient ξ is found to be less than $3.78\ \mathrm{stat}coul^{-1}\cdot m^{-1}\cdot\mathrm{kg}\cdot\mathrm{sec}$. There is still a question of whether the value ξ actually exists or zero; we may be able to obtain a more accurate measurement from a setup with no feedback systems in place, that is, no beam energy compensation systems, beam orbit correction systems, and so on.

Furthermore, the EGI coefficient $\xi \leq 3.78\ \mathrm{stat}coul^{-1} \cdot m^{-1} \cdot \mathrm{kg}\ \cdot \mathrm{sec}$ can also be formulated using the existing constants, G and κ_e:

$$\xi \leq 9.77 \times 10^{-4} \left(\frac{1}{c} \sqrt{\frac{\kappa_e}{G}} \right) \tag{8}$$

where G is the gravitational constant, κ_e is the dielectric constant, and c is the speed of light in a vacuum. From equation (6), we see that the resulting value of ξ would be less than that obtained above, if the EGI does in fact exist.

Conclusions

In this paper, we have postulated the existence of electro-gravitational induction (EGI) in a particle storage ring. The expected changes in particle paths obtained from our model coincide with the results of the terrestrial tidal force model. By neglecting the effects of tidal forces and the synchronization and feedback systems of the storage ring, and making use of the existing COD signals from the LEP, SPring8, and APS *(1-3)* facilities, we found that the induction coefficient ξ should be less than 3.78 $\mathrm{stat}coul^{-1} \cdot m^{-1} \cdot \mathrm{kg}\ \cdot$ s, if the EGI don't exists, then ξ=0. The electro-gravitational induction described above is weak. The charged particles move in turns through the large accelerator storage ring at approximately the speed of light, which produces an energy change. The movement of charged particles can accumulate the effects of electro-magnetic induction such that they become observable. We have presented this idea of electro-gravitational induction, which is an interesting and valuable quantity to investigate in detail; however, we could not conclusively determine the existence of a gravity induced electric field. We image two rings at the same place, one is the positive particles ring and the other is negative particles ring, and the both two kinds of particles move in the same direction, under the EGI prediction, we should observe the energy increases of one kind particles while the other decreases at same time; the corresponding particle path will then have an opposite change. At same place means the terrestrial tide force make the same changes to the positive and negative particles ring. This is different from the terrestrial tidal force model. So we can measure $\Delta\mathrm{COD(t)}$, $\Delta\mathrm{COD(t)} = \mathrm{COD_+(t)} - \mathrm{COD_-(t)}$, $\mathrm{COD_+(t)}$ is the closed obit distortion of the positive particles beam and $\mathrm{COD_-(t)}$ for the negative particles beam. Therefore, $\Delta\mathrm{COD(t)}$ signals will be independent on the terrestrial tidal force. For example, based BEPC, the Beijing Electron and Positron Collider, have two rings, one is electron ring and the other is positron, if we modify the machine so that the electron and positron beam moves at the same direction in the two ring, then we can check the EGI model by measuring $\Delta\mathrm{COD(t)}$, in future. Furthermore, EGI may also explain the clouds be charged the deferent charges.

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