Potential for a new muon g-2 experiment

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A new high-precision experiment to measure the muon g-2 factor is proposed. The developed experiment can be performed on an ordinary storage ring with a noncontinuous and nonuniform field. When the total length of straight sections of the ring is appropriate, the spin rotation frequency becomes almost independent of the particle momentum. In this case, a high-precision measurement of an average magnetic field can be carried out with polarized proton beams. A muon beam energy can be arbitrary. Possibilities to avoid a betatron resonance are analyzed and corrections to the g-2 frequency are considered.

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I. INTRODUCTION

Measurement of the anomalous magnetic moment of the muon is very important because it can in principle bring a discovery of new physics. Experimental data dominated by the BNL E821 experiment, $a^{exp}_{\mu\pm} = 116592080(63)\times 10^{-11}$ (0.54 ppm), are not consistent with the theoretical result, $a^{the}_{\mu\pm} = 116591790(65)\times10^{-11}$, where $a = (g-2)/2$. The discrepancy is 3.2σ: $a^{exp}_{\mu\pm} - a^{the}_{\mu\pm} = +290(90)\times 10^{-11}$ [1]. In this situation, the existence of the inconsistency should be confirmed by new experiments. The past BNL E821 experiment [2] was based on the use of electrostatic focusing at the "magic" beam momentum $p_m = mc/\sqrt{a}$ ($\gamma_m = \sqrt{1 + 1/a} \approx 29.3$). An upgraded (but not started up) experiment, E969 [3], with goals of $\sigma_{syst} = 0.14$ ppm and $\sigma_{stat} = 0.20$ ppm is based on the same principle.

Since the muon g-2 experiment is very important, a search for new methods of its performing is necessary. One of new methods has been proposed by Farley [4]. Its main distinctions from the usual g-2 experiments are *i*) noncontinuous magnetic field which is uniform into circular sectors, *ii*) edge focusing, and *iii*) measurement of an average magnetic field with polarized proton beams instead of protons at rest. A chosen energy of muons can be different from the "magic" energy. Its increasing prolongs the lab lifetime of muons. As a result, a measurement of muon g-2 at the level of 0.03 ppm appears feasible [4].

In the present work, we develop the ideas by Farley. We adopt his propositions to measure the average magnetic field with polarized proton beams and to use a ring with a noncontinuous field for keeping the independence of the spin rotation frequency from the particle momentum. We also investigate the most interesting case when the beam energy can be arbitrary. However, we propose to perform the high-precision muon g-2 experiment on an ordinary storage ring with a nonuniform field created by superconducting magnets. We prove that the independence of the spin rotation frequency from the particle momentum can be reached not only in a continuous uniform magnetic field [2, 3] and a noncontinuous and locally uniform one [4] but also in a usual storage ring with a noncontinuous and nonuniform magnetic field. In the last case, the total length of straight sections of the ring should be appropriate. We also analyze possibilities to avoid the betatron resonance $\nu_x = 1$ (ν_x is the horizontal tune) and consider corrections to the g-2 frequency.

The system of units $\hbar = c = 1$ is used.

II. g-2 RING WITH A NONCONTINUOUS MAGNETIC FIELD AND MAGNETIC FOCUSING

Let us consider spin dynamics in a usual storage ring with a noncontinuous magnetic field and magnetic focusing. The general equation for the angular velocity of spin precession in the cylindrical coordinates is given by (see Ref. [5])

$$\boldsymbol{\omega}^{(a)} = -\frac{e}{m}\Biggl\{a\boldsymbol{B} - \frac{a\gamma}{\gamma+1}\boldsymbol{\beta}(\boldsymbol{\beta}\cdot\boldsymbol{B}) + \frac{1}{\gamma}\left[\boldsymbol{B}_{\parallel} - \frac{1}{\beta^2}\left(\boldsymbol{\beta}\times\boldsymbol{E}\right)_{\parallel}\right] + \frac{\eta}{2}\left(\boldsymbol{E} - \frac{\gamma}{\gamma+1}\boldsymbol{\beta}(\boldsymbol{\beta}\cdot\boldsymbol{E}) + \boldsymbol{\beta}\times\boldsymbol{B}\right)\Biggr\}, \quad \boldsymbol{\beta} = \frac{\boldsymbol{v}}{c}. \qquad (1)$$

Eq. (1) is useful for analytical calculations of spin dynamics with allowance for field misalignments and beam oscillations. This equation does not contain small terms which can be neglected. $\eta = 4dm/e$ is an analogue of the g factor for the electric dipole moment, d. The sign $\parallel$ denotes a horizontal projection for any vector. Thereinafter, the electric dipole moment will be disregarded. The vertical magnetic field, B_z, is the main field in the muon g-2 experiment. The spin precession caused by this

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