THESIS ABSTRACT

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目　　录

BEPC miniβ Lattice 方案设计及纵向微波不稳定性的初步研究

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摘　要

本文通过对 BEPC Low－β 设计方案和现物理实验区边界条件的研究，设计和比较了 BEPC 实施 Mini－β 各种可能的方案。在考虑单对撞点对撞的前提下，通过对南、北两对撞点都实施 Mini－β 的 MM 结构和只在南对撞点实施 Mini－β 的 LM 结构的比较研究，认为 LM 结构比 MM 结构动力学孔径更大，动力学参数调节也更容易，因而确定了BEPC实施 Mini－β 的结构为LM 结构。设计了 BEPC Mini－βLM 结构的电磁插入铁方案（电磁铁方案）和永磁插入铁方案（永久磁铁方案），通过计算和研究，指出了永久磁铁方案在BES和插入铁磁场的屏蔽、插入铁的安装调试、束流孔径以及费用等方面比电磁方案有着突出的优点，并通过模拟环上有永久磁铁时能量 ramp 的实验证明了永久磁铁方案无能量 ramp 丢束的问题。对永久磁铁方案进行了优化，计算了能量 ramp 过程中束流参数的变化情况和北区结构、工作点、对撞能量对对撞模式的影响以及实施 Mini－β 对同步辐射专用模式的影响。永久磁铁方案优化在注人能量为 1.6GeV，对撞能量为 2.0GeV，永久磁铁长度为 0.5 米，中心距对撞点 1.58 米，场梯度为 8T/m，北对撞区保持现 Low－β Lattice 结构不变，对撞模式在南对撞点 β 为3.6cm，β 为1.2m，工作点 $\nu x = 5.8$ $\nu y = 6.8$，发射度为0.66mmmrad，永久磁铁优化方案对撞模式动力学孔径为 $25\sigma_x$ $25\sigma_y$，$10\sigma_e$，耦合可校正到 0.7%，计算亮度可达 $2.4\times10^{31}cm^{-2}s^{-1}$，亮度提高因子为2～3。对注人和 SP 分开的研究也表明，永久磁铁方案在注人和 SP 分开方面不存在困难。

本文还探讨了通过虚γ_t磁铁结构压缩束团长度和抑制纵向不稳定性随流强快速增长(Fast blow up)的方法。初步计算了一个BEPC Mini－β的虚γ_t Lattice并和常规Lattice做了比较。通过对纵向微波不稳定性Fast blow up的进一步研究，指出对于阻抗为宽带阻抗的大多数储存环(对撞机)，$\alpha_p<0$ (虚γ_t)时无微波不稳定性的 Fast blow up发生。

文中还初步计算并比较了Mini－β永磁方案优化模式，虚γ_t模式和现Low－β运行模式在势阱，纵向coherent模mode coupling等方面的情况，在束团较长，计算模型误差较小时计算的现Low－β运行模式mode coupling阈值为25mA，比较接近于实际的阈值(15mA左右)，并指出了虚γt模式mode coupling阈值在同样束长和高频电压的情况下比常规模式mode coupling阈值高。

Scheme Design of the Miniβ Lattice and Research to the Longitudinal Microwave Instability

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ABSTRACT

Different mini $-\beta$ schemes for Beijing Electron Positron Collider (BEPC) are studied through detail investigation into the BEPC operation (low $-$ beta) lattice and the boundary condition for mini $-\beta$ insertion. With the prerequisite of applying single IP colliding to the mini $-\beta$ lattice design, LM configuration which has mini $-$ p insertion only in the Southern IP is preferable to the MM one which has mini $-\beta$ insertion in both Southern IP and Northern IP since that LM configuration is more flexible in adjusting lattice parameters and has larger dynamic aperture. The Electromagnet mini $-$ beta scheme and the permanent magnet mini $-\beta$ scheme with LM configuration are designed. Comparison between the electromagnet mini $-\beta$ scheme and permanent magnet mini $-\beta$ scheme demonstrates that the permanent magnet mini $-\beta$ scheme has many advantages over the electromagnet mini $-\beta$ scheme, such as eliminating the shielding between the insertion quadrupoles and the detector, simplifying the installation and adjustment of the insertion quadrupoles and saving expenses.

Through the study of different magnet pattern in the Northern IP region, the preferred pattern is the one that the Northern IP region is kept the same as that of the low $-\beta$ scheme. The permanent magnet mini $-\beta$

scheme is optimized with the working point of $\nu_x = 5.8$, $\nu_y = 6.8$, and with the natural horizontal emittance to be 0.66 mmmrad. The computing results and the simulated test shows no difficulty with the permanent magnet mini - beta scheme in energy ramping. A simple simulation of particles injecting into the ring indicates no aperture problem in accumulating and the investigation into beam separation and affection to the synchrotron dedicated operation points out no problem.

A new method, called the imaginary focusing, for shortening the zero current bunch length and weakening the longitudinal microwave instability or fast bunch lengthening is investigated in order to help the using of mini - β scheme. An imaginary lattice for BEPC is calculated and its properties are compared with the conventional lattice.

The potential - well effect and the longitudinal mode coupling of the mini - β model, the imaginary model and the present operation model are computed with a broad band impedance. The calculated threshold current for the present operation model meets the actual value when the error of the calculated model is not large enough to distort the calculation and the threshold current of imaginary model shows much higher than that of the conventional one. The further study of microwave fast blow up also makes clear that there is no microwave fast blow up in an imaginary storage ring if the impedance is broad band impedance or a pure capacitor.

多层膜介面粗糙度对 X 射线反射和散射的影响

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摘　要

人工合成生长的多层膜，其正入射反射率(百分之几十)比单个表面正入射反射率(~ 10^{-4})提高了几个量级，这种特性大大推动了软 X 光光学的发展，并已应用于很多领域，如 X 射线天文学、显微学、等离子体诊断、X 射线光刻、同步辐射光学等。这种合成材料具有不同于其组成体材的光学、电学、磁学、机械和超导等特性，然而这些特性都是与界面的结构分不开的，原子尺度上的界面质量强烈影响多层膜的这些特性及其在诸多方面的应用，如粗糙界面将引起反射率的减小，利于成像和光谱学的应用。镜面反射强度的减少增加了弥散强度的增加，从而减小成像系统的衬度。界面粗糙不仅影响了多层膜的各种特性及其应用，而且一般来说，在制膜技术中是很难避免的。确定界面结构及其造成的影响，对理解和控制多层膜的物理特性，是一项非常重要的工作。

在这篇论文中，我们对多层膜界面粗糙度的来源及其数学表述形式作了介绍。界面的不完美是由多种原因引起的，探讨其来源有助于对界面粗糙度有更清楚的认识，对界面的定义及粗糙情况的数学描述是研究其对 X 射线反射、散射影响的第一步。

粗糙界面对 X－ray 反射的影响已有了很多的工作，但人们在处理由于粗糙界面引起的多层膜反射率的减小时，最常用也最简单的办法是对理想界面的反射率乘上一个 Debye－Waller(D－W)因子的修正。这种方法的前提是假定每个界面的平均粗糙度是相同的，且每个界面的高度分布是 Gaussian，所以这种方法只能告诉我们一个总的平均粗糙度的值。由于轻重元素交替生长而导致的不同界面 A/B、B/A 粗糙程度差异对反射的影响考虑的却很少。在这篇论文中，基于运动学衍射理论，分

析了界面 A/B 与 B/A 粗糙度不等时对反射的影响，并得到了一个新的不同于 DW 因子的衰减因子，可以根据不同的界面分布情况，给出不同的分布函数来计算它对反射率的影响，并且在满足消光条件时，反射强度的计算值不为零。考虑到测量中角度零点偏差的存在，讨论了如何用两衍射峰峰位之差来减小零点偏差对计算周期 d 时的影响，并给出了数学表达式。同时对我们自己制备的 6# W Si 样品的实验结果做了拟合计算，得到了满意的结果。

X 射线散射是研究多层膜结构中界面粗糙情况的一种相当有效的技术。最近，X 射线非镜面散射(nonspecular scattering)对多层膜中界面粗糙度的研究引起了人们极大的兴趣。首批实验结果表明这种 X 射线散射可以揭示界面之间结构相关的一系列特性。由于这是一个刚被注意到的新领域，所做的工作还不多，还存在一些不完善的地方。虽然单个粗糙界面对 X 射线散射的理论可以在文献中见到，但对多层膜的粗糙界面的非镜面散射的理论处理尚有很多不足之处。本文对粗糙界面的非镜面散射问题作了详细的讨论。每个界面考虑有四支散射波的贡献，计算总的散射强度时，没有简单的将各界面散射振幅相干叠加，而是用动力学处理方法将每只散射波乘上一个出射因子，出射因子是由动力学中的迭代方法计算的。在总的散射强度中还考虑了镜面散射的贡献，从而在计算中得到了 rocking curv 中尖锐的镜面峰。在上述考虑问题的基础上对现有的理论进行了修改和完善。实验方面作了 2θ、rocking curve、offset($\theta, 2\theta$)等非镜面散射的测量。用修正后的公式计算的结果与实验值相比取得了很好的一致。

现有的动力学衍射理论处理多层膜的 Bragg 反射大多数是基于单个界面散射的 Fresnel 方程的迭代和矩阵方法，而以 Darwin 动力学衍射理论来处理的却很少，本文将晶体动力学衍射的 Darwin 理论运用到多层膜对称 Bragg 反射中，给出了一系列解析表达式，可计算强度比、反射曲线角宽度、最小周期数及能量分辨率等。对实验结果进行了模拟并与迭代方法计算的结果进行了比较，取得了很好的一致。

反射率的测量是软 X 光多层膜质量检测的一个重要手段。本文利用安装在北京同步辐射装置 3B1 束线上的一台小型反射率计，对磁控溅射方法制备的软 X 光多层膜进行了 R ～ θ、R ～ λ 两种反射率测量，得到实测反射率高达 32% 的满意结果，同时给出了理论计算对实验的拟合，二者符合的很好。

常规的 X 射线衍射的多层膜测试是很重要的。作者在一台 12KW 转靶 X 光机

的基础上，从光路设计到步进马达、数据采集等一套控制系统的建立，搭置了一台二圆衍射系统，并利用它做了大量的多层膜样品测量工作，并取得了一批有用的实验数据.

Effect of Interfacial Roughness of Multilayer on X-ray Reflecting and Scattering

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ABSTRACT

A synthetically grown multilayer structure can produce normal incidence reflectance of tens of present at X-ray wavelengths, several orders of magnitude greater than the reflectance of a single surface(10-4). This property has spurred the development of a new class of reflection optics for the soft X-ray, and it is used in many applications, such as X-ray astronomy, microscopy, plasma diagnostics, X-ray lithography optics and X-ray optics of synchrotron radiation. The artificial multilayered structures have a range of unique optical, electrical, magnetic, mechanical, and superconducting properties different from either of the component materials. Such properties depend on atomic-scale interfaces at the layer boundaries. For example, the interfacial roughness leads to a loss of specular reflectivity, which is detrimental in both imaging and spectroscopy applications. This loss of specular reflectivity appears as an increase in the diffusely scattered radiation, leading to a loss of contrast in imaging system. The interfacial roughness not only affects the properties of multilayer structure, but also presents in all multilayer fabricated by any method. Therefore, it is essential and of practical importance for understanding and controlling the physical properties of multilayers to determine the detailed structure of the interfaces and its effect.

In this thesis, we present the sources and mathematics description of the interfacial roughness. There are a number of possible causes to induce the imperfection of interfaces. To make clear the sources is helpful to have a clear knowledge on the interfacial roughness. Giving a definition of interface and mathematics description of the roughness, it is the first step to study the effect of the interfacial roughness on X-ray reflecting and scattering.

Many works about the effect of the imperfection of interfacial roughness on X-ray reflection can be found elsewhere. By multiplying reflectivity of a perfect multilayer with a Debye-Waller factor, it is the simple and usual method to deal with the reduction of reflectivity caused by the interfacial roughness. The method is assumed that the distribution of heights of one or the other material at each interfaces is a Gaussian and average interfacial roughness is the same for each interface. Therefore, this method simply tells us a total average roughness of a multilayer. It is seldom considered the impaction of the difference of the interfacial roughness between interfaces A/B and B/A due to the alternating deposition of heavy and light elements. In this thesis, based on kinematical X-ray diffraction theory, a distribution function of interfacial roughness in the reciprocal space is introduced in a formula of a structure factor. Considering that the interfacial roughness of a light element A on a heavy element B is different from the one in the inverse order, a new correcting factor different from the Debye-Waller factor is obtained. According to various distribution, different distribution functions can be used for the calculation. When the Bragg condition is fulfilled, the calculated reflectivity is not equal to zero, this point can not been obtained by use of the usual method with a Debye-Waller correcting factor. A fitting is made to the experiment result of 6# W/Si sample, and the result is satisfactory. In order to eliminate the systematic error caused by zero point calibration of incident angle, we use the difference of two diffraction peak positions for the determination of period of a multilayer.

X－ray scattering is an effective technique for characterizing the roughness of surfaces and interfaces in multilayer structure. More recently there has been great interest in using nonspecular X－ ray scattering to study the roughness of interfaces. The first experimental results indicate that the X－ray scattering can exhibit a rich variety of behavior associated with the structural correlations between interfaces. However, it is a new field, so the correlated works are not much, and there are still some imperfection in the present works. Although the theory of scattering from a single toughness surface can be found in the literatures, there are still some drawbacks in the theoretical treatment of the nonspecular scattering from multilayer. In this thesis, we present a detailed discussion on the problem. It is considered that there are four contributions to the nonspecular field from each interface, the scattered power is not simply estimated as the sum of the nonspecular scattering from each interface, it is treated by dynamic diffraction method through multiplying a transmission factor which is calculated by the recursive method. In addition, a term of specular scattering is also taken into account in the expression of the scattered power, so we can obtain a sharp peak in the rocking curve in our calculation. Based on the above consideration, it is done to improve and complement the previous theory. On experimental aspect, detailed X－ ray nonspecular scattering measurements are performed. The scan methods are, rocking curve and offset. Calculation based on the corrected formulas in carried out for rocking curve and it is in good agreement with the measurement.

Most of the dynamic theory of X－ray diffraction for multilayer are originated from the Fresnel equations for the scattering from a single interface in conjunction with recursive or matrix methods to treat the multiple scattering within the multilayer. Few publications followed the Darwin's theory of dynamic X－ray diffraction to describe the scattering processes of soft X－rays. In this thesis, introducing the Darwin's method of treating X－ray diffraction in crystals into Bragg diffraction for multilayer, a series of analytical expressions are obtained which can be used to calculate the reflectivity, the Darwin's width, the minimum number of periods and the energy resolution. The calculated result agrees with the experiment and the recursive simulation very well.

Reflectivity measurement is an important aspect of reflecting the quality of soft X－ray multilayer. Taking use of two kinds of measurements of reflectivity versus wavelength and reflectivity versus incident angle are carried out, a satisfactory result of reflectivity of 32% is obtained. A fitting with theoretical calculation which is consistent with the experimental data.

A conventional two－circle diffraction system is set up. The work includes the design of light route, the establishment of control system of stop motor and data collection, and the adjustment of the facility. a number of multilayers are measured using the diffractometer and a lot of useful experimental data are obtained.

J/ψ 辐射衰变到 5γ 终态的研究

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摘 要

基于北京正负电子对撞机(BEPC上的北京谱仪(BES)获取的约 $8X10^6 J/\psi$ 事例，主要分析了 $J/\psi\to\gamma X\to 5\gamma$。

对 J/ψ 中性事例的质量和簇射计数器的 cluster 进行了细致的研究，得到的结论是，某些 cluster 的能量和坐标测量的错误及 cluster 的分裂和重叠不影响分析结果。

分析了被其他实验组研究得很清楚的 $J/\psi\to\gamma\pi^0,\ \gamma\eta,\ \gamma\eta'\to 3\gamma$，得到的 π^0、η 和 η'的质量及在 π^0、η 和 η'处的质量分辨为

$$M_{\pi^0}=137.5\pm3.8MeV/c^2 \qquad \sigma=14.8\pm3.2MeV/c^2$$
$$M_{\eta}=546.3\pm1.2MeV/c^2 \qquad \sigma=18.6\pm1.1MeV/c^2$$
$$M_{\eta'}=958.6\pm3.7MeV/c^2 \qquad \sigma=23.4\pm3.8MeV/c^2$$

使用 $J/\psi\to\gamma\eta$ 分支比的 PDG 值，$8.6X10^{-4}$，给出从 Run766 到 Run3738 的 J/ψ 总数为$(7.90\pm0.69)X10^6$，使用此J/ψ 总数，测量的 $J/\psi\to\gamma\pi^0$ 和 $J/\psi\to\gamma\eta'$的分支比分别为

$$B(J/\psi\to\gamma\pi^0)=(4.52\pm1.20\pm0.72)X10^{-5}$$
$$B(J/\psi\to\gamma\eta')=(4.84\pm0.69\pm0.67)X10^{-3}$$

这些值在实验误差范围内与 PDG 值一致。

$J/\psi\to\gamma\pi^0,\ \gamma\eta,\ \gamma\eta'\to 3\gamma$ 分析的成功，说明 BES 组能重复别的实验组研究清楚了的工作，是进一步工作的基础。

研究了 $J/\psi\to\gamma X\to\gamma\pi^0\pi^0\to 5\gamma$。测量的 $f_{2(1270)}$、$f_{2(1720)}$ 和 X(2100)的质量和宽度及分支比为

$f_{2(1270)}$ $\quad M=1.275GeV/c^2$ fixed

$\Gamma = 0.185 GeV/c^2$ fixed

$B(J/\psi \to \gamma f_2(1270))B(f_2(1270) \to \pi^0\pi^0)$

$= (2.79 \pm 0.40 \pm 0.46) X10^{-4}$

$f_2(1720)$ $M = 1.717 \pm 0.016 GeV/c^2$

$\Gamma = 0.104 \pm 0.038 GeV/c^2$

$B(J/\psi \to \gamma f_2(1720))B(f_2(1720) \to \pi^0\pi^0$

$= (8.50 \pm 3.00 \pm 1.53) X10^{-5}$

X(2100) $M = 2.097 \pm 0.041 GeV/c^2$

$\Gamma = 0.287 \pm 0.225 GeV/c^2$

$B(J/\psi \to \gamma X(2100))B(X(2100) \to \pi^0\pi^0)$

$= (1.15 \pm 0.97 \pm 0.23) X10^{-4}$

这些值在实验误差范围内与 Crystall Ball 和 DM2 组的结果一致。

用螺旋度振幅法和矩分析法两种方法分析了 $f_2(1270)$ 和 $f_2(1720)$ 的自旋，结果如下，螺旋度振幅法：

$f_2(1270)$ $J^{pc} = 2^{++}$

$x = 0.62 \pm 0.09$

$y = 0.07 \pm 0.09$

$f_2(1720)$ $J^{pc} = 2^{++}$

$x = 0.64 \pm 0.17$

$y = -0.37 \pm 0.25$

矩分析法

$f_2(1270)$ $J^{pc} = 2^{++}$

$f_2(1720)$ $J^{pc} = 2^{++}$

使用这两种方法得到的结果是一致的。过程 $J/\psi \to \gamma f_2(1270) \to \gamma\pi^0\pi^0$ 的螺旋度振幅参数在实验误差范围内与 Crystall Ball 和 DM2 组的结果一致。

本文第一次分析在 $J/\psi \to \gamma\pi^0\pi^0$ 过程中观察到的 $f_2(1720)$ 的自旋并给出其自旋为 2。

研究了 $J/\psi \to \gamma X \to \gamma\eta\eta \to 5\gamma$。在 $\eta\eta$ 低质量区，观察到两个明显的峰 $f_2'(1525)$ 和 X(1770)。$f_2'(1525)$ 和 X(1770) 的质量和宽度及测量的分支比为

$f_2'(1525)$ $M = 1.545 \pm 0.017 GeV/c^2$

$\Gamma = 0.064 \pm 0.032 GeV/c^2$

$B(J/\psi \to \gamma f_2'(1525))B(f_2'(1525) \to \eta\eta)$

$=(3.[illegible]2 \pm 1.30 \pm 0.76)\times10^{-4}$

X(1770)　$M = 1.768 \pm 0.030 GeV/c^2$

$\Gamma = 0.100 \pm 0.073 GeV/c^2$

$B(J/\psi \to \gamma X(1770))B(X(1770) \to \eta\eta)$

$=(2.47 \pm 1.44 \pm 0.82)X10^{-4}$

没有观察到GAMS组发现的G(1590)，估计其产生上限为

$B(J/\psi \to \gamma G(1590))B(G(1590) \to \eta\eta) < 5.89X10^{-4}$　　90% C. L.

在$\eta\eta$高质量区，在2.2GeV/c^2处观察到一窄峰X(2.2)，其统计意义为3.0σ，假设它是一共振态，其质量及估计的分支比分别为

$M = 2.204 \pm 0.022 GeV/c^2$

$B(J/\psi \to \gamma X(2.2))B(X(2.2) \to \eta\eta) = (1.73 \pm 1.07 \pm 0.49)X10^{-4}$

分析了在$J/\psi \to \gamma\eta\eta$, γk^+k^-, $\gamma k^s_0 k^s_0$过程中观察到的X(2.2)和χ(2.2)的自旋，结果都是0^{++}可以排除，2^{++}稍微优于4^{++}。由于统计量低，螺旋度振幅参数不能准确测量。

X(2.2)可能是χ(2.2)。

提出了许多f_2(1720)及χ(2.2)的解释，但没有定论。