Supporting and driving system for in-vacuum undulator

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Abstract Two in-vacuum undulators have been developed for the first time in China at Shanghai Synchrotron Radiation Facility (SSRF), which has been opened to users since May, 2009. The precision of mechanical system is important to ensure performances of magnetic field. Efforts were made to manufacture in-vacuum undulator with high mechanical properties. The taper mechanism is adopted for the first time in the design of an in-vacuum undulator. A finite element analysis was performed to find out the deformation of out-vacuum girder and minimize the effect of linear rolling guide on it. In this article, the design and analysis results for the in-vacuum undulator are described.

Key words In-vacuum undulator, Taper mechanism, Mechanical design, FEA

1 Introduction

Shanghai Synchrotron Radiation Facility (SSRF), a third generation synchrotron light source[1] with a storage ring of 432 m in circumference running 3.5 GeV and 300 mA beam bunches, has been opened to the users in May, 2009. It has 20 straight sections for installing electron-beam injection, radio-frequency (RF) and insertion devices. In Phase I of the SSRF project, seven beamlines and five insertion devices were built, including two wigglers, one elliptically polarizing undulator (EPU100) and two in-vacuum undulators (IVU25). The two in-vacuum undulators are of the same design, in period length of 25 mm and minimum gap of 6 mm, covering the photon energy range of 3.5–22.5 keV with up to the 11th harmonic. One is used for macromolecular crystallography (MC), and another for hard X-ray micro-focusing (HXM)[2]. The two in-vacuum undulators are installed in Cell 15 and Cell 17 of the storage ring, as shown in the rectangular area in Fig.1.

An in-vacuum undulator requires a highly reproducible motion of gap and mechanical stability to produce high quality lights. The factors considered in the mechanical design usually include the cost, rigidity, practicality, assembly, physical limits, and so on. Efforts were made to balance the manufacturing cost and the requirements of high mechanical stability, rigidity and reproducible motion of gap. The main parameters that have great impact on the mechanical design are given in Table 1.

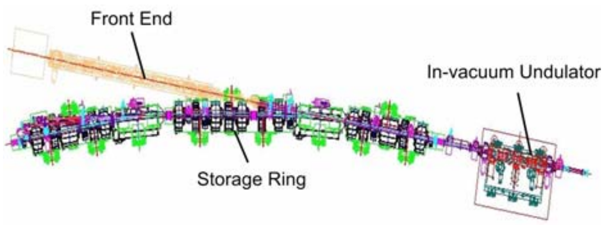

Fig.1 Space position of IVU25 in storage ring.

Table 1 Main parameters of mechanical design of IVU25

Parameters	Values
Min. / Max. Gap / mm	6 / 25
Max. magnetic force load / kN	20
Max. girder deformation / μm	≤±3
Gap adjustment accuracy / μm	≤1
Taper control / μm	≤±2
Vertical alignment accuracy / μm	≤±160
Horizontal alignment accuracy / μm	≤±500

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2 Mechanical design descriptions

Generally, the main-frame of an in-vacuum undulator can be of a *C*-type or *H*-type structure. A *C*-type IVU is better in our case, because an *H*-type IVU demands a larger space, despite its superior mechanical properties[3]. Fig.2 shows 3D views of IVU25, with most of the components, i.e. the adjusting system, supporting frame, driving system, encoder system, out-vacuum girder and compensating spring system being designed by mechanical group and the vacuum system being designed by the vacuum group.

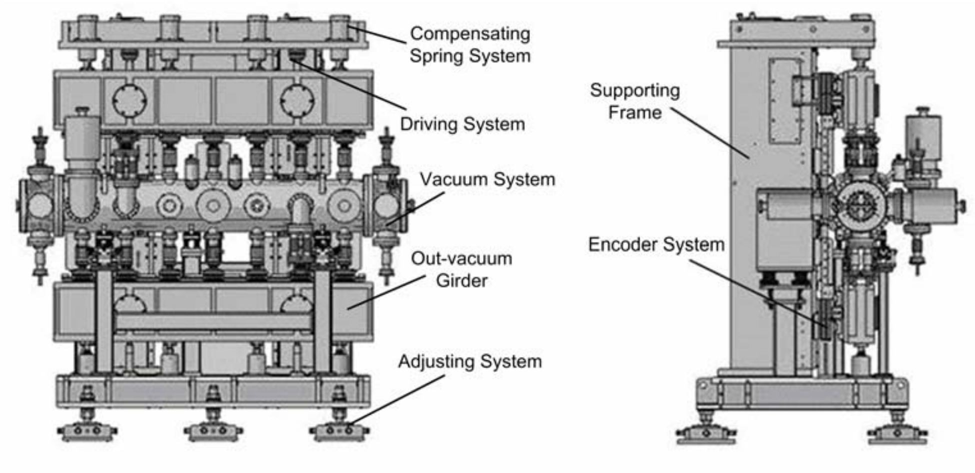

Fig.2 The 3D views of IVU25.

2.1 Supporting frame

In order to withstand large magnetic force, it is necessary to have a simple but stiff supporting frame. Two vertical supporting columns with good mechanical stability and rigidity are molded as boxes in rectangular shape by welding individual steel plates together. The columns provide the framework for holding and driving the magnet arrays.

2.2 Driving system

As shown in Fig.3, the driving system consists of ball screw spindle, gear box, linear rolling guide, coupling, precision bearing, and stepper motor with a girder's movement accuracy of 0.25 μm per step. There are two sets of ball screw spindles that are supported by precision bearings mounted on the columns and are driven by the stepper motor. The ball screw spindle is right-handed on the upper section, and left-handed on the lower section, so as to provide an equal but opposite vertical motion of upper and lower out-vacuum girder. The ball-nut is connected with the ram that supports the out-vacuum girder.

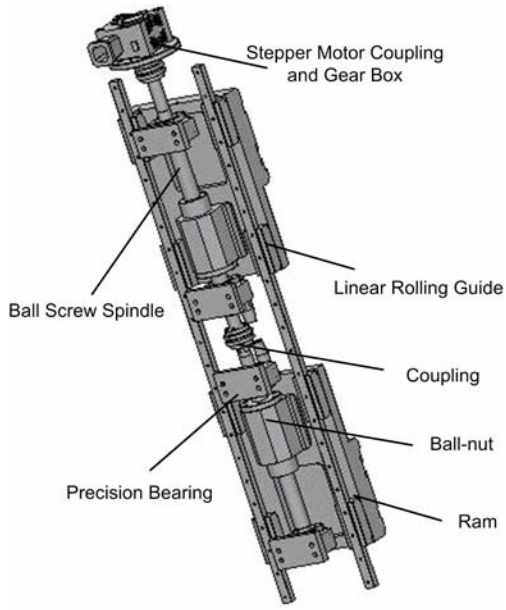

Fig.3 Driving system of IVU25.

2.3 Taper mechanism

The IVU works in two modes: the non-taper mode, in which the two out-vacuum girders are parallel; and taper mode, in which the two out-vacuum girders are titled. The taper mechanism is designed to satisfy the two working modes. As shown in Fig.4, the out-vacuum girder is supported by two overhanging shafts. One is bolted to the ram on the upstream and another is connected with ram by linear rolling guides on the downstream. The out-vacuum girder can move up and down by means of the sliders located behind of the rams, and the non-taper mode is achieved. Also, the out-vacuum girder can rotate around the shafts and move along the beam direction on the downstream, and in this way, the taper mode is achieved. The taper mechanism allows a reproducible mechanical gap taper in the range of −500 to 500 μm. In addition, the taper mechanism, limit switch and gap motion stopper play an important role in protecting the IVU25 in case of losing driving control.

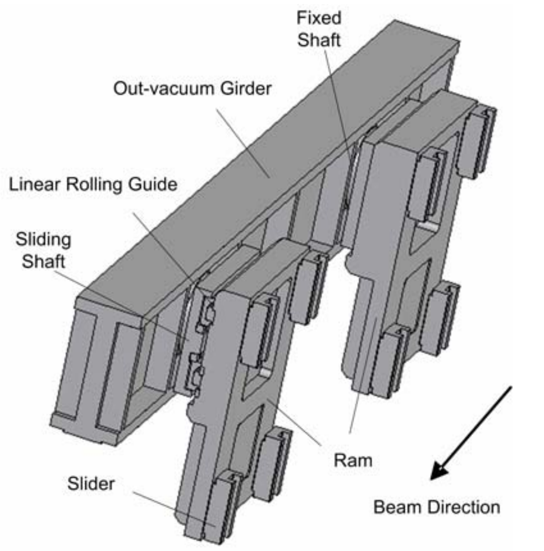

Fig.4 Taper mechanism.

3 Engineering calculations

The purpose of engineering calculation is to estimate the deformation of out-vacuum girder and find out the effect of linear rolling guide on it. For the high-performance magnetic field, the mechanical structure must be in accord with the parameters in Table 1 and strong enough to be equipped with the magnet arrays. This requests that the girder deformation under powerful magnetic forces does not exceed a given limit, which is in micrometers.

3.1 Girder analysis

The out-vacuum girder is reduced to an extensional beam model as shown in Fig.5, when m is equal to $0.4082l$, the maximum deformation of the beam can be expressed as:

$$f = \frac{q \cdot l^4}{384 \cdot E \cdot I}$$

where f is the deformation, q is the load per unit length, E is the modulus of the elasticity, I is the moment of the inertia, and l is the distance between the two support points. For IVU25, the total length of the out-vacuum girder is 2.1 m and the distance between two supports is 1.156 m.

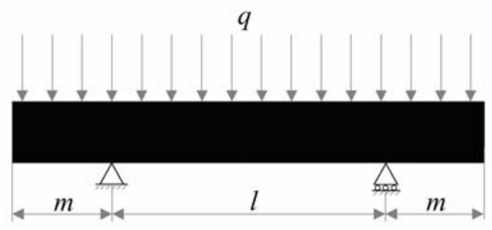

Fig.5 Schematics of a uniformly loaded extensional beam.

3.2 Taper mechanism analysis

The linear rolling guide would weaken the stiffness of taper mechanism and bring about asymmetric deformation to out-vacuum girder, therefore, it is necessary to analyze the deformation of out-vacuum girder and the effect caused by the linear rolling guide with finite elements method (ANSYS[4]).

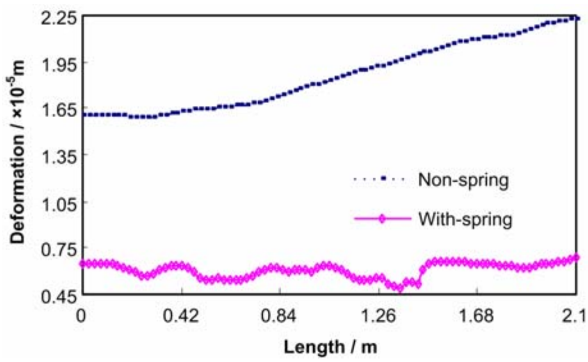

Fig.6 Deformations of upper out-vacuum girder under magnetic gap of 6 mm.

In the process of building finite element model, the linear rolling guide joint is designed as a spring-damper unit which includes tangential spring and normal spring[5]. When the magnetic gap is 6 mm and the magnetic force reaches its maximum value of 20 kN, the deformation of out-vacuum girder on the downstream will be 22.3 μm and 6.4 μm, larger than that on the upstream because of linear rolling guide, as shown in Fig.6. Furthermore, the deformation of out-vacuum girder is greater than the specification in

Table 1. In order to reduce the deformation of out-vacuum girder, the compensating spring system, which consists of two disc springs and two ring springs, is used to alleviate the out-vacuum girder load[6]. Because magnetic force is nonlinear, each spring is adapted to select the suitable coefficient and magnet gap, from which it starts to work. Fig.6 indicates that the deformation of out-vacuum girder becomes smaller and the scope of variation gets smaller too, though the deformation is still a little greater than the specification.

4 Conclusion

The taper mechanism is used to control taper in the design of in-vacuum undulator for the first time. Compared with traditional taper controller which is driven by stepper motor[7], the taper mechanism is more convenient and flexible to control taper. Two in-vacuum undulators were installed in the store ring of SSRF and provided steady light for experiment stations. The mechanical performance of the IVU25 meets the stations' specifications preferably.

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