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VIBRATION ANALYSIS OF STORAGE RING GIRDER FOR THE KOREA 4GSR*

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Abstract

Ensuring the mechanical stability of the girder for a 4th generation storage ring (4GSR) is crucial to provide a high-quality photon beam to users because the mechanical motion should be maintained at less than 10 % of the electron beam size which is expected to be sub-micrometer. One of the key roles of the girder is to provide structural rigidity and temperature stability while effectively suppressing vibrations from the ground during accelerator operation. The Korea 4GSR girder is being designed to have the first natural frequency above 50 Hz to minimize the effect of the ground vibration. In order to maintain better mechanical stability, it is necessary to conduct research not only on the natural vibration evaluation of the girder but also on external vibrations to the girder structure. In this paper, we introduce the result of the harmonic analysis of the girder structure using the finite element method.

INTRODUCTION

The Korea 4GSR girder system is designed to conform to a storage ring circumference of approximately 800 m to conform to stable accelerator design variables. Alignment mechanisms such as motor-driven cam moves, wedge jacks, and motor-driven wedge jacks are used in the case of circular synchrotron accelerator girder systems that are driven worldwide. The girder system for the PLS-II of the third-generation circular accelerator used an alignment mechanism through screw jacks to secure a wide driving range and mechanical rigidity [1]. The Korea 4GSR girder system was developed using a ball screw jack with improved moving accuracy and durability instead of the existing TM screw jack for the girder body adjustment. In addition, it was developed using a motor control drive and a displacement sensor for convenience in precise alignment of the accelerator [2]. This research explains the design concept of Korea 4GSR and structural design to secure rigidity [3], natural frequency evaluation [4], and structural stability due to random frequency [5] using Finite element analysis (FEA) to analyse mechanical characteristics.

Requirement for the Girder System

Beam physical requirements must be satisfied for the design of the Korea 4GSR girder system. In the global cases where upgrades from 3rd generation to 4th generation circular accelerators have been made, vibration characteristics of the ground and characteristics of the accelerator building should be reliably identified in order to build a successful synchrotron accelerator. Korea 4GSR should be operated stably for the external environment, and development that meets the following requirements should be carried out for the girder system.

- Electron beam height: 1.4 m.
- High flatness of girder top and low deformation for installation and operation of accelerators.
- Securing high primary resonant frequencies for limited conditions.
- Motor driven alignment mechanisms.
- Optimal girder design for free space in storage-ring tunnels.
- Securing mounting holes for installing various devices.
- Ensuring thermal stability.

The main parameters for developing the girder system of Korea 4GSR are as follows.

Table 1: Main Parameters for the Girder System [6]

Parameter	Value	
Number of cells	28	cells
Circumference	798.8	m
Beam height	1.4	m
Levelling range (Vertical)	± 10	mm
Lowest natural frequency	50	Hz
Adjustment method	Motorized (Vertical)	
Positioning accuracy	± 10	μm

Design Layout

The girder design is heavily influenced by the beam physics design and device configuration. There is a total of 28 cells at about 800 m around the storage ring, and the types are normal cells and high beta injection (HBI) cells, each cell was developed into five girders. The layout of the girder system is also composed of two types because the normal cell consists of symmetrical upstream and downstream based on the central bending section, and the HBI cell has a non-symmetric configuration [7]. There are three types of girder for installing the storage ring accelerator. All girder adjustment devices are designed in the same mechanism with 4 points motor-driven in the Y direction and 3 points in the X and Z directions being manually adjusted. For a normal cell, three girders based on the center of each cell are designed to be 4.8 m in the longitudinal direction, and the girders at both ends of the cell are designed to be 3.8 m. The HBI cell is designed with the three

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girders in the center of each cell at 4.8 m, the upstream direction girders at 3.4 m, and the downstream direction girders at 3.8 m long. Figure 1 shows a girder system that includes an electromagnet on the beam path.

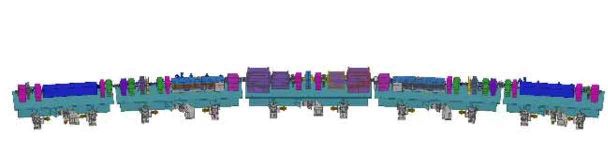

Figure 1: Design of the girder in the achromat.

METHODOLOGY

The center bending magnet girder model was used to analyse the overall mechanical stability. Mechanical characteristic analysis has consisted of a self-weight analysis of gravity, a natural frequency analysis of the girder structure itself, and a random frequency analysis of external vibrations. In order to obtain the FEA results, the analysis results were confirmed using the Ansys 2022. In addition, Vibration data of the Korea 4GSR site was obtained using an accelerometer of 10 V/g to acquire ground vibration data that could affect the accelerator. Figure 2 shows the comparison of the Korea 4GSR accelerator ground vibration measurement data and the vibration criteria (VC) [8] with the 1/3 octave rms value of the accelerator site.

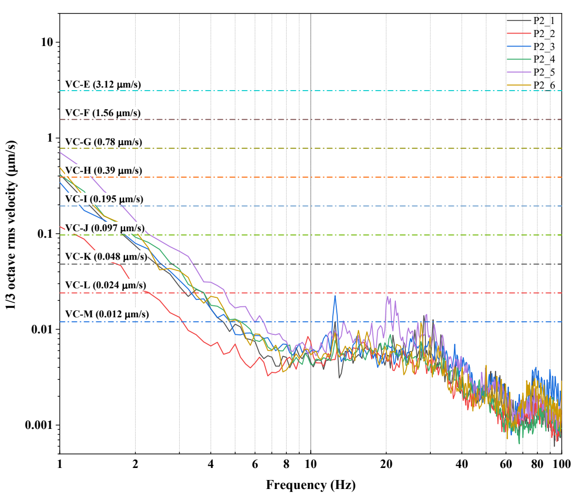

Figure 2: Comparison of the ground vibration and VC.

RESULT

Static Analysis

Static analysis to identify deformation due to gravity was evaluated for two cases: conditions by girder itself and a girder system including a vacuum chamber and a magnet. In order to proceed with the static analysis, the analysis was carried out, including the properties of the material constituting the girder system and the boundary conditions of the elements constituting the adjustment system. The results of the interpretation can be seen in detail in Fig. 3. The first case is the interpretation of the girder itself. As a result of this analysis, the maximum displacement of the girder system is 18.4 µm, and it can be confirmed that the maximum displacement occurs at the center point in the beam length direction, which is the center of gravity of the girder body. In the second case, an analysis was performed considering the weight such as a magnet and vacuum chamber on the top of the girder system. The maximum displacement from the origin of the girder design was confirmed to be 60.9 µm. It was confirmed that the maximum displacement point occurred at the end of the girder body and a displacement of 54 µm occurred on the girder top plate. The displacement of the girder endpoint is the result of not considering the center of gravity of the magnet and the appearance of the accelerating device, and detailed verification is required based on the prototype that is scheduled to be manufactured. The results of analysing the displacement amount and displacement point of the girder system through static analysis will enable the installation and operation of the circular synchrotron accelerator to a level that can be accurately measured and aligned with the girder system during the construction.

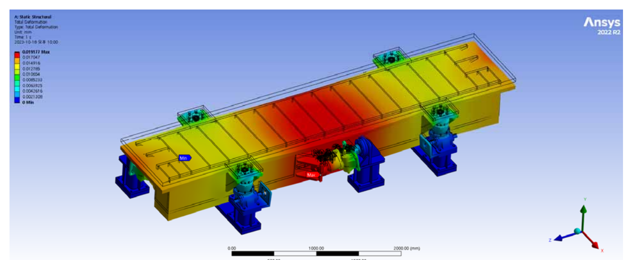

Figure 3: Deformation analysis of the girder system.

Modal Analysis

Displacement and vibration propagation of the storage ring girder system affect the trajectory of the accelerated beam, causing the performance of the circular accelerator to deteriorate. For ESRF-EBS, it aims to maintain the vibration stability of the mechanical system below 10 % of the electron beam size. Vibration stability through error study of beam physics will be presented in Korea 4GSR, and a system with rigidity should be secured while maintaining vibration stability caused by external vibration in the girder system for this purpose. Based on the existing girder components, the 4GSR girder system has been improved to secure mechanical rigidity and vibration suppression capabilities by utilizing the rib for reinforcing rigidity.

Considering the structure and material characteristics of the girder system, research should be conducted to study the dynamic characteristics of the girder system and to increase the 1st natural frequency inside the structure. The design of the girder vibration part was carried out through modal analysis based on linear vibration theory and finite element techniques. Analysing the dynamic characteristics of the girder can be used as basic data to avoid resonance and reduce displacement.

The modal analysis of the girder system confirmed that the 1st natural frequency was more than 58 Hz, which shows a higher natural frequency characteristic than the girder system design goal of 50 Hz. Evaluation of the natural frequency of the accelerator devices is an important

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factor in securing the stability of the beam. Since the amount of displacement amplified when high-frequency band resonance occurs in the accelerator is less than when resonance occurs at low frequencies, research on how to increase the natural frequency of the girder system and suppress external vibration should be conducted continuously. In particular, the natural frequency results are expected to be guidelines that can minimize the frequency effect of peripheral devices or facilities generated during beam operation as well as the external vibration.

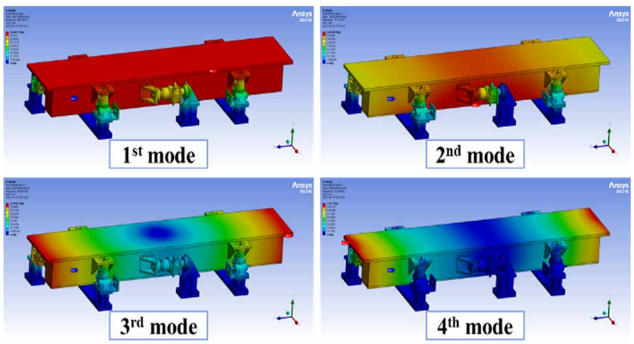

Figure 4: Modal analysis.

Table 2: Frequency of Difference Distortion Modes

Mode	Frequency [Hz]	Mechanical Property
1st	58.08	Transversal translation
2nd	71.17	Transversal + Roll
3rd	90.68	Translation beam Dir.
4th	122.96	Torsional

Random Vibration Analysis

In order to analyse the effect of the girder system on the ground vibration of the synchrotron accelerator site, ground vibration data was obtained by using an accelerometer of 10 V/g measuring level. The power spectral density (PSD) data of the ground measured as shown in Fig. 5 was confirmed to be at an appropriate level compared to the fourth-generation circular accelerator currently operating globally. The average displacement of RMS from 1 to 100 Hz was 2.7 to 12.8 nm through the ground vibration measuring. Civil engineering work is underway in the Korea 4GSR area and the data measured was considered to have been affected by variable environmental factors. It is expected that more reliable data can be obtained when the ground formation of the accelerator is completed.

When evaluating random vibration by applying external vibration variables to the center bending girder, the displacement of the top plate could be seen around 28 pm as shown in Fig. 6. In particular, a result value of a very low strain of 20 pm was calculated in the center of the girder top plate. This value is less than 10 % of the Korea 4GSR Beam size which can sufficiently function as a girder system.

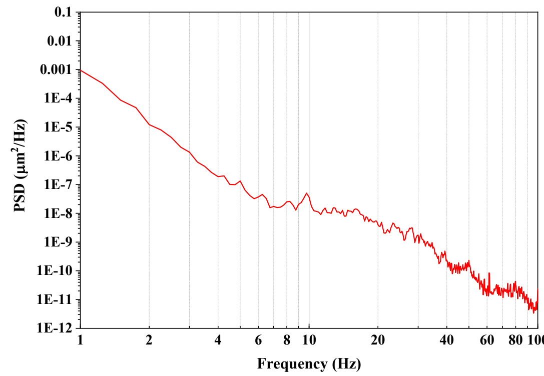

Figure 5: Ground vibration response.

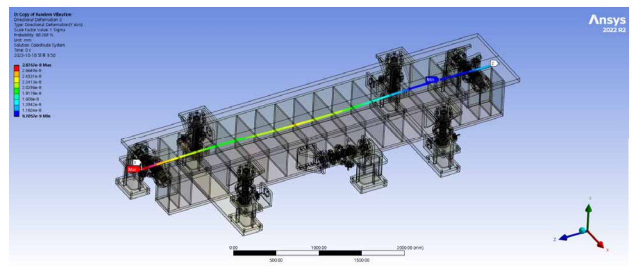

Figure 6: Random vibration analysis.

CONCLUSION

FEA for the girder system was performed to investigate the structural characteristics. The gravity analysis based on its own weight, the displacement of the girder itself was confirmed to be at the level of 18 μm and 54 μm when the magnet was included. In the natural frequency analysis, the first natural frequency was confirmed to be 58 Hz or more. The floor stability in all locations is remarkably well placed with respect to the common VC curves, with integrated displacement between 1 and 100 Hz below in the range from 2.7 to 12.8 nm RMS. The random vibration analysis results that can affect the beam operation were confirmed at 28 pm on the girder top plate which was confirmed that less than 10 % of the beam size would not affect the operation. Based on the results of this study, it is expected that more complete results will be derived by acquiring data through field experiments through measurement and prototypes in an improved environment for the development of the girder system.

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