Nuclear Inst. and Methods in Physics Research, A 887 (2018) 184–192

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

A GEM readout with radial zigzag strips and linear charge-sharing response

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ARTICLE INFO

Keywords:
GEM
Zigzag readout strip
Flex readout foil
Linear response
Spatial resolution

ABSTRACT

We study the position sensitivity of radial zigzag strips intended to read out large GEM detectors for tracking at future experiments. Zigzag strips can cover a readout area with fewer strips than regular straight strips while maintaining good spatial resolution. Consequently, they can reduce the number of required electronic channels and related cost for large-area GEM detector systems. A non-linear relation between incident particle position and hit position measured from charge sharing among zigzag strips was observed in a previous study. We significantly reduce this non-linearity by improving the interleaving of adjacent physical zigzag strips. Zigzag readout structures are implemented on PCBs and on a flexible foil and are tested using a 10 cm × 10 cm triple-GEM detector scanned with a strongly collimated X-ray gun on a 2D motorized stage. Angular resolutions of 60–84 μrad are achieved with a 1.37 mrad angular strip pitch at a radius of 784 mm. On a linear scale this corresponds to resolutions below 100 μm.

1. Introduction

The concept of zigzag-shaped readout pads was first proposed for gaseous time projection chambers (TPC) in the 1980s in order to reduce the number of electronic channels required to read out the detector [1]. Later, MWPCs and GEMs were read out with parallel zigzag strips and good spatial resolutions were achieved [2,3]. This was confirmed in more recent studies which showed that the spatial resolution of a small GEM detector with parallel zigzag strip or zigzag pad readout can approach 70 μm [4,5], a performance comparable to the ≈50 μm resolution that GEM detector readouts with parallel rectangular strips can achieve [6]. We subsequently introduced radial zigzag strips to read out trapezoidal large-area GEM detectors [7], which are intended for tracking systems at future experiments, e.g. forward tracking at the electron ion collider (EIC) [8]. Radial zigzag strips can precisely measure the ϕ coordinates of incident particles in order to track them and to determine their transverse momenta in a solenoidal field.

In our previous studies [5,7], we observed a non-linear relation between incident particle position and hit position measured from charge sharing among radial zigzag readout strips. This paper aims at quantifying the non-linear response of our previous zigzag designs and at demonstrating an improved zigzag design that has a linear response. A linear response ensures the accuracy of hit position measurements without the need for any corrections. For this purpose, six readout boards with different geometrical zigzag strip structures are produced and tested using a 10 cm × 10 cm triple-GEM detector on a 2D motorized stage. The incident particle position is defined by a highly collimated X-ray beam (140 μm × 8 mm collimator slit) in these measurements.

2. Zigzag readout strip designs and test boards

As shown in Fig. 1, zigzag strips can be designed by connecting certain points on strip center lines and reference lines in certain patterns. Four parameters are used to calculate the coordinates of these points: the start radius of the strips, the period of the zigzag structure in the R direction (a fixed number of 0.5 mm in our studies), the ϕ–angle pitch between strips (1.37 or 4.14 mrad in our studies), and a fraction f of the angle pitch which defines the reference lines and determines the width, space, and interleaving of the zigzag strips [9]. There are two ways to use these points. In the first design method shown on the left in Fig. 1, a strip is outlined by points on a strip center line and two reference lines near it. In the second design method shown on the right in Fig. 1, a strip is outlined by points on the two center lines of neighboring strips and on the two reference lines. The "interleaving" of strips can be defined as $(1-d/p)\times 100\%$ in Cartesian coordinates, where d is the distance

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https://doi.org/10.1016/j.nima.2017.12.074
Received 26 August 2017; Received in form 23 December 2017; Accepted 26 December 2017
Available online 10 January 2018

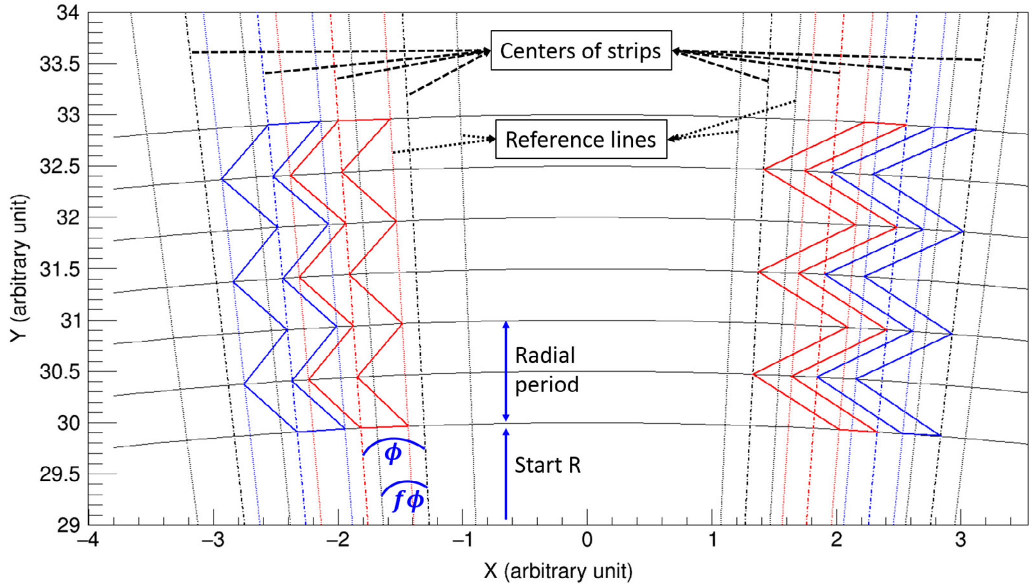

Fig. 1. A sketch of radial zigzag strip designs indicating the four parameters that define the strip geometry. Here ϕ is the angular strip pitch and f is the fractional strip pitch parameter that determines the strip shape. The thicker dashed lines represent centers of the strips, each center line of a strip has two reference lines to its left and right with an angle of $f\phi$. The tips of a strip on the left do not exceed its two reference lines, while the tips of a strip on the right reach the centers of its neighboring strips.

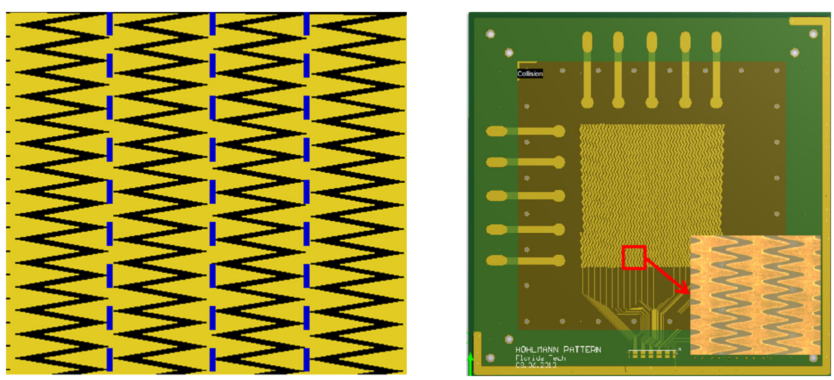

Fig. 2. Left: The original zigzag strip design that was used in our previous study [7]. The dashed blue lines represent the center lines of each zigzag strip. The angle pitch is 1.37 mrad, the period of the zigzag structure in the R direction is 0.5 mm and the fraction parameter f is 0.75. Right: The full readout PCB layout created in Altium Designer for 48 zigzag strips with this design. The strips have radii from 1420 to 1520 mm. The inset picture shows a region from the actually produced PCB, which demonstrates that the physical strips have a "spine" along their centers.

between the right tips of the left strip neighbor and the left tips of the right strip neighbor, and p is the strip pitch. In Fig. 1, the design on the left has an interleaving between 0% and 100% (because $d < p$) while the design on the right has 100% interleaving (because $d = 0$). It is expected that the 100% interleaving design gives better charge sharing and a more linear position response.

Fig. 2 (left) shows the zigzag design produced with the first design method that was used in our previous study [7]. The angle pitch was 1.37 mrad, the period of the zigzag structure in the R direction was 0.5 mm and the fractional strip pitch parameter was $f = 0.75$. Two printed circuit boards (PCBs) with this design were produced by industry (Fig. 2 right): one with 48 strips of radii from 1420 to 1520 mm ("ZZ48 board"), the other with 30 strips of radii from 2240 to 2340 mm ("ZZ30 board"). The strip length on both boards was 10 cm except for strips near the edges of the active area and the strips on each board covered an area of approximately 10 cm × 10 cm. As can be seen in the inset in Fig. 2 (right), the physical strips on the manufactured boards had a "spine" along the center of each strip due to low manufacturing precision in the etching of sharp points and corners. Also the space between strips turned out to be wider than what had been designed. No effort was made to further improve the quality of these two boards.

Instead, we produce and test new zigzag strip boards with the "100% interleaving" design (Fig. 3 left). For versatility, each board is designed with two different radial strip geometries. On the left side of the board, the radial strips are arranged with an angle pitch of 4.14 mrad and starting radius of 206 mm, while on the right side of the board radial strips are arranged with an angle pitch of 1.37 mrad and starting radius of 761 mm (Fig. 3 right). We choose these two particular parameter sets because they correspond roughly to the inner and outer radial sections of a large-area trapezoidal GEM detector design for an EIC forward tracker prototype. They also have similar linear strip pitches around 1 mm. The two other design parameters, period of the zigzag structure in the R direction and fraction parameter f, are kept the same at 0.5 mm and 0.4, respectively. The strips are again about 10 cm long except for those near the edges of the active area. The capacitance between two adjacent zigzag strips is measured to be (22 ± 2) pF and the capacitance between a strip and the readout board ground is measured to be (28 ± 2) pF. The errors here reflect strip-to-strip variations in the measurement.