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THE DEFORMATION-STRESS SIMULATION AND MEASUREMENT OF TITANIUM FOIL STRIP FOR HADRON MONITOR

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Abstract

The measurement of beam profile by hadron monitor is in fact the measurement of the positive current after the secondary electrons escaped. According to the situation that the number of beam particles (10^{11}/s) is small and the current signal is weak, the material titanium with high secondary electron generation rate is select by material comparison, and the foil strip type is used to increase the cross section area to obtain lager current level. On account of dead weight itself, as well as thermal expansion and contraction, the foil strip shall be loose. The loosen strip will deviate from its theoretical position, and cause the measuring error. Therefore, the deformation-stress of Ti foil strip (1000*50*0.1) was simulated under the pretension (10~90N) with the finite element software ANSYS. A set of experiment device with pretension adjustment and heating for the foil strip was designed, and then the deformation-stress was tested by a high precision 3-D imaging measurement system. Compared with the simulation results, the pretension would better set at about 50N.

INTRODUCTION

When possessed with sufficient kinetic energy generated by beam particles bombardment, electron of the signal wire would overcome and escape from the surface potential barrier, these are secondary electrons. The measurement of beam profile by hadron monitor is in fact the measurement of the positive current after the secondary electrons escaped. Because the signal proportionally depends on the number of particles, many wires distributed in X/Y direction of hadron monitor can bring out the beam profile.

During the operation time, the monitor is inserted into the beam area, and the signal wire has a semi-blocking effect on the beam, resulting in beam scattering and energy loss. Partial of the lost energy will deposited in the wire, which can cause heating and temperature rising. On account of dead weight of signal wire itself, as well as thermal expansion and contraction, the wire shall be loose. The loosen wire will deviate from its theoretical position, and cause the measuring error [1].

To sum up, for ensurance of sufficent accuracy requirement, it is necessary to carry out the simulation and measurement on the position accuracy of the wire with corresponding measure, such as pretension.

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MATERIAL AND STRUCTURE

During the development of SEM (secondary electron monitor), various materials were analyzed and compared by Fermi Lab. The results indicated that Ti has not only excellent mechanical strength and thermal performance to meet the measurement needs, but also high secondary electron production rate which appears to maintain its secondary electron yield even after lager particle fluences [2-3]. So, Ti is chosen as the material of signal wire.

For collection of secondary electron signal, the shape of structure is also deserved more consideration. Because the quantity of beam particles in the position of hadron monitor is relatively small, beam profile needs to be measured by the method of weak current [4].

The emission of secondary electrons mainly occur in a very thin layer on the surface, which is related to the properties of the incident particle (such as elements, energy and incident angle) and surface state (such as surface adsorption layer, etc.). According to the Sternglass theory, the order of magnitude of secondary electron yield can be estimated:

$$Y = \frac{P \cdot d}{E^*}\frac{dE}{dx} \tag{1}$$

In which Y is the secondary electron yield, P is the generation probability of secondary electron, d is the average depth of secondary electron generated, and E^* is the average kinetic energy deposited by each single ionized particle, dE/dx is nuclear retardation ability.

Secondary electronic signal generated can be calculated:

$$I_{SEM} = Y \cdot \eta \cdot I_{beam} \tag{2}$$

η is the ratio of the intercepted beam, $\eta = \frac{\delta_{wire}}{\sqrt{2\pi}\sigma_{rms}}$ (δ_{wire} is the wire diameter) [1].

From the above, changing the signal wire structure from cylinder into foil strip can greatly increase the ratio of interception beam by increasing the cross section area, which can improve the level of secondary electronic signal and obtain higher measurement sensitivity accordingly.

DEFORMATION-STRESS SIMULATION

In order to obtain appropriate secondary electron

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signal, according to the given physical parameters (protons per pulse 10^{12}, beam spot size 6mm, beam energy 60/120GeV, pulse duration 1.6μm, cycle time 10s), the dimension of Ti foil strip is determined to 1000*50*0.1(mm). In this state, the max working temperature by simulation is about 313K, and we also take 333K in consideration for safty. Due to the linear expansion of Ti is about $10.8*10^{-6}$/K, the deformation caused by thermal expansion will up to 0.216mm should not be ignored. So, a structure with pretension adjusting must be designed for the long term serviced foil strip to prevent the loosen condition.

Figures 1 and 2 show the vertical deformation and stress simulation results of Ti foil strip with one end fixed at 313K under pretension of 50N .

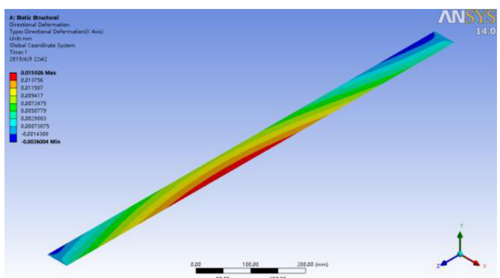

Figure 1: The vertical deformation of Ti foil strip at 313K under pretension of 50N.

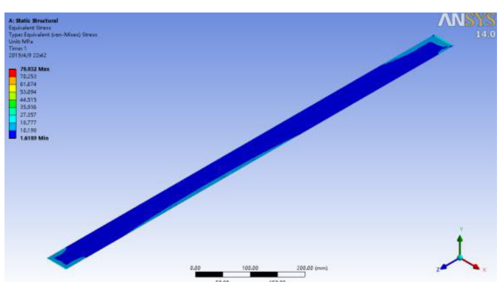

Figure 2: The equivalent (von-mises) stress of Ti foil strip at 313K under pretension of 50N.

Figures 3 and 4 show the vertical deformation and stress simulation results of Ti foil strip at 313K and 333K under different pretensions. As shown in figure 3, with the increase of pretension, the vertical deformation of foil strip decreases, but the variation is very small (μm level). For temperature parameter, the vertical deformation increased only 5μm from 313K to 333K. It indicated that temperature has very little effect on vertical deformation of foil strip under pretension.

As shown in figure 4, with the increase of pretension, the max equivalent (von-mises) stress of Ti foil strip decreases. It should be the dominant role of thermal stress caused by temperature. On the basis of von-mises yield criterion, the stress caused by pretension will counteract part of thermal stress. Therefore, the max equivalent stress decreases with the pretension increasing. Moreover, it was found that the max equivalent stress increased with the increase of the pretension when it is increased up to more than about 1800N (as well as without thermal stress), which proved the analysis results were reliable.

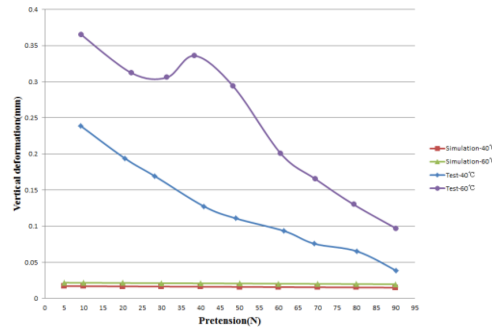

Figure 3: The vertical deformation of Ti foil strip at 313K and 333K under different pretensions.

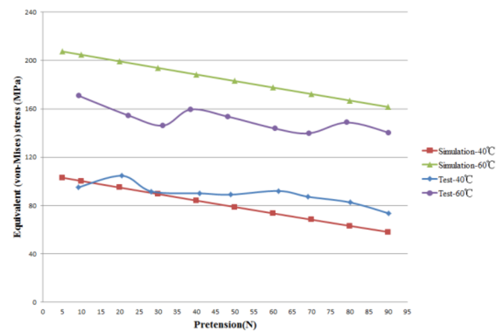

Figure 4: The max equivalent (von-mises) stress of Ti foil strip at 313K and 333K under different pretensions.

On the working condition of temperature 333K and pretension 5N, the max equivalent stress of Ti foil strip is up to 204MPa, which is very close to the yield strength (275MPa). For actual design, the pretension must be much greater than the gravity of strip, not less than 5N, meanwhile, considering the difficulty of structure technology, pretension also shall not be larger than 90N.

EXPERIMENTAL TESTING DEVICE

In order to verify the simulation results, one set of experimental testing device were designed and manufactured to perform the deformation-stress test, and to provide a basis reference for the following design of strip tighten structure of hadron monitor.

Figure 5 shows the deformation-stress experimental testing device of Ti foil strip. The dynameter is connected to foil strip through strip fixer, and the pretension is adjusted by the terminal end screw and nut. Meanwhile, the dynameter is mounted on the slide block and moved along the guide rail to prevent the distortion of tension value caused by misalignment between dynameter direction and measuring direction. The foil strip is heated by quartz heating tube on the broadside, and the temperature is measured and controlled by infrared thermal sensor.

Figure 6 shows the 3-D imaging measurement system for deformation-stress. The speckle image on the foil strip is tracked by two cameras to measure the displacement

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and strain. The data processing is completed by computer, and the measurement accuracy is better than 0.02mm.

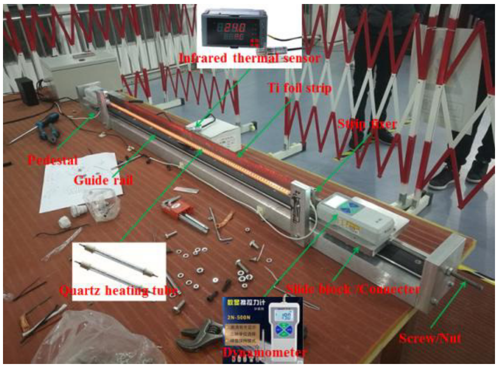

Figure 5: Experimental testing device.

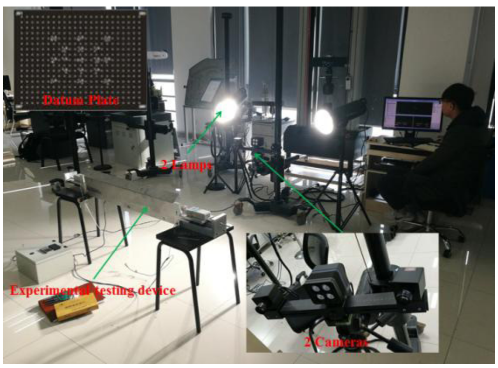

Figure 6 : 3-D imaging measurement system.

Measurement steps are as follows: 1. Calibrate the measurement system with datum plate; 2. Spray speckle points onto Ti foil strip; 3. Adjust the tension to 50N, and complete the measurement of datum position; 4. Heat the foil strip up to 313K and 333K respectively, adjust tension (10~90N) on one side, and take photos to track the speckles by each process every 2s.

TEST AND MEASUREMENT

Pick out the max value of displacement and strain in every test process, compare with the simulation result, which basically proves the reliability of experimental result.

Figure 3 shows the graph of max vertical deformation obtained by tests. The max vertical deformation of Ti foil strip decreases with pretension increasing, which is consistent with simulation result, however, the measured results are much larger than the simulation result. The probably reason is that, for the heated foil strip, temperature of boundary edge along the vertical direction (50mm) is much lower than center region, which caused the curl of foil strip. We can find that this situation is in accordance with the deformation at 333K larger than at 313K. The max vertical deformation is abnormally large for 333K at 40N. It is caused by the manually adjusted pretension which exceed 40N, once redressed back to 40N, previous deformation could not respond in a real-time manner.

Figure 4 shows the graph of max equivalent (Von Mises) stress obtained by experimental test. The max equivalent stress decreases gradually with pretension increasing, which is also consistent with the simulation results. At 313K, the max equivalent stress obtained by test are similar to the simulation results; but at 333K, the test ones are less than simulation results. There maybe two possible reasons: 1. Cameras could not extract the max stress position exectly, as figure 2 shown, to perform accurate collection and measurement, so error inceases by temperature arise; 2. The position of max equivalent stress is far away from the heating region and thermal sensor, and the termperature of that position will lower than 333K, so are the measured results.

For ensure the foil strip having enough accuracy (vertical deformation less than 0.15mm) and stress having a sufficient safety factor, as well as mechanical construction technology in concideration, the pretension had better set at about 50N.

CONCLUSION

According to the situation that current signal is weak, the current enhanced by method of material comparison and selection, as well as structure modification is described in this essay. Deformation-stress simulation of Ti foil strip, experimental test device, test and comparison works are completed to ensure the measurement accuracy, and the pretension determined as 50N finally.

Several issues were found during test process, which should be improved in the following work: 1. Motor controlled shall be applied to ensure the accurate tension; 2. The effect of tiny deformation on tension should be ignored by adding spring; 3. The temperature should be precisely controlled by using chip resistor. As the continuous testing work in the further, it will provide some guidance for the structure design of Ti foil strip of hadron monitor.

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