NUMBERICAL ANALYSIS OF STRESSES FOR THE TARGET OF THE ILC 300 HZ CONVENTIONAL POSITRON SOURCE *

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Abstract

A 300Hz conventional, e- driven positron source for the ILC is proposed by an international team. In this paper, we focus on numerical analysis of dynamic stresses in the Tungsten target. These are driven by the pulsed e-beam, which causes rapid heating and subsequent, dynamic loads in the target which can lead to fracture and failure of it. A program of ANSYS workbench is used in the study. The dynamic stresses from both of extremely short (10 ns) and nominal (1μs) thermal pulses are systematically studied in various target related parts such as small spheres, cylinders. Particular attention has also been paid to the buckling of foils.

INTRODUCTION

The International Linear Collider (ILC) [1] is an electron positron linear collider project. To achieve the high luminosity of 2×10^{34} $cm^{-2}s^{-1}$ at E_{CM}=500GeV, it will accelerate high current beams with pulse of 1ms duration consisting of about 2600 bunches of positrons or electrons. The baseline choice of ILC positron source is helical undulator scheme [2]. However, this scheme gives interconnection to nearly all sub-systems of the ILC. It will be a challenge to design and operation of this system. Besides, strict constraints are also given to the positron source, taking for example, the requirement of 2600 bunches in 1ms will bring a heavy target heat load.

To reduce the thermal load in the positron target, a 300Hz conventional, e- driven positron source for the ILC is proposed by an international team [3]. In this study, by using a program called ANSYS Workbench, numerical analysis are carried on for the fundamental study of dynamic stresses at various kinds of. On one hand, the results will be helpful to well understand the characteristics of the thermal effect of target and give a direction for the initial physical design of the target as well as later optimization. On the other hand, basic study of simulation can be easier judged whether the used methods are optimized or even correct. For the later real complicated target system, those knowledge are necessary to the related analysis.

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ANALYSIS OF STATIC MODELS

Study firstly begin with static model. Firstly, it will help to understand a normal status after thermal load. Secondly, it is also give a tendency for the dynamic analysis results after a long time.

The cylinder is shown as fig. 1. It is an axisymmetric tungsten cylinder with 10 mm diameter and 20 mm length. Left one in fig.1 shows a uniform temperature of 200 C, and its diameter is 5mm as red part. Two boundary conditions are studied as following:

- Constrained in the two ends but free at radial direction. It means that we have boundary constrain for line 1 and line 3, and there is no line 2.
- Constrained in the two ends and at radial direction. It means that we have boundary constrain for all of the line 1, line 2 and line 3.

The right one in fig. 1 the inner part has a linear decreased temperature along radius. It also is radially free but constrained at the two ends. We choose 600C for maximum temperature at centre, and then decrease to 0, linearly. The reason why choose 600C is because the energy is the same as which is uniform 200C.

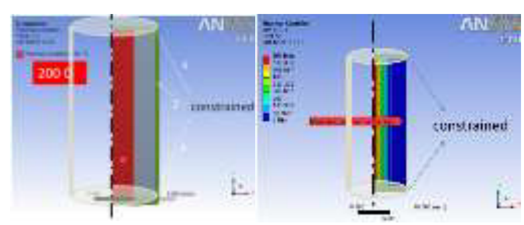

Figure 1: Cylinder model for static analysis.

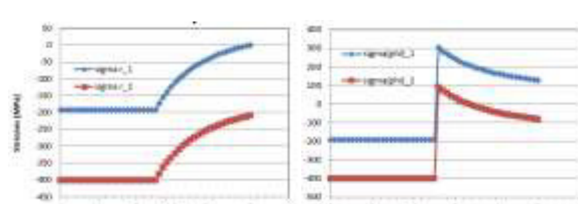

Figure 2: Results of stresses of sigma r, sigma phi for the model of left picture of figure 1.

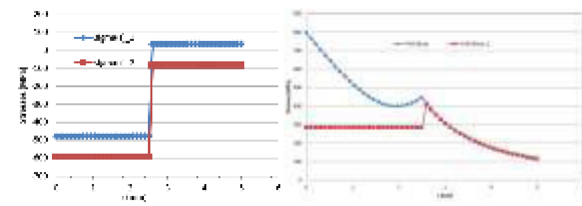

Figure 3: Left is the result of stresses of sigma z for the model of left picture of figure 1; right one is the result of the model of right picture of figure 1.

Results of stresses of sigma r, sigma phi and sigma z for the model of left picture of figure 1 are shown in figure 2 and right picture of figure 3. The blue colour represents the results with boundary of radially free, while the red colour are the results with boundary constrained at line 1, 2, and 3.

The blue line in right picture of figure 3 shows the results of the model which has a linear temperature distribution. The red colour line represents the results from uniform temperature model.

From comparison of those results, following conclusion can be obtained:

The cases which have a uniform temperature in inner part: 1) stresses at the inner part are also uniform; 2) stresses sigma r and sigma pi have same value at inner part; 3) all the three stresses sigma r, sigma pi and sigma z have the negative value at inner part due to thermal expansion.

For the cases have uniform temperature profile, but one is radially free, and the other constrained: 1) the variation tendency is the same for all the stresses in r, phi and z direction; 2) but the three stresses of sigma r, phi and z have a uniform differences in the two cases; 3) however, what interesting is v. M. Stresses are the same in the outer parts in the two cases.

For the case that has a linear temperature distribution but same energy at the inner part, also radially free: 1) The stresses are also not uniform at inner part; 2 Stresses sigma r and sigma pi will not have the same value except at the point of r=0; 3) But all the stresses are the same at the cold part as results of the case uniform temperature and radially fee.

SHOCK STUDY

Shock study is more important for us comparing with the static status. This is because usually from a thermal pulse, the transient stress can be much greater that in the static status. The study mainly focused on the sphere and cylinder models. Due to symmetrical characteristic, the shock results of sphere usually are clear and easy to compare with some value of the theoretical analysis. Besides, granular target is also a possible choice for the design. So, a shock study of sphere is carried out. Moreover, we also carried out the shock study for cylinder because the shape has a greater possibility for the design.

Shock Study on Sphere

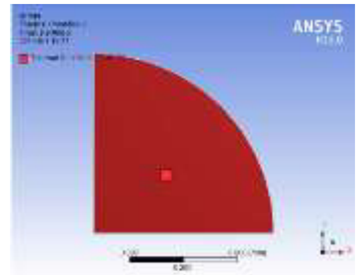

Figure 4: Sphere model used in the simulation. Material of the sphere is also tungsten. Temperature is uniform in the volume; it is 220 C after heating; Diameter is 2mm.

Due to the symmetrical characteristic, we can use the model shown in figure 4 for the simulation. It is a tungsten ball with a volume uniform temperature of 220 C. The diameter is 2mm.

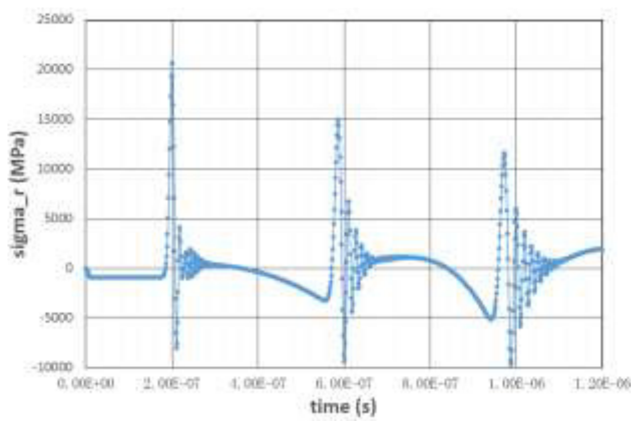

Figure 5: At centre, stress of sphere of sigma r development with time due to 1ns thermal pulse for the sphere model.

Figure 5 shows the stress of sigma r development with time at the centre of sphere. This shock comes from a 1ns thermal pulse. The peak value of the pulse is 220C. From the picture, we can see for the initial 10ns, the stress decrease linearly. This is because for the first 10ns, the energy come linearly. So, there will be a stress in the centre. Another we would like to mention is the stress is negative. Due to the thermal expansion, the centre will have a pressure from outside. So, the stress will be negative. After that, there is a platform since there is no energy increase. But at about 0.2 µs, the stress has a sharp increase. This is because the stress from outside boundary has transferred two the centre. Due to the velocity of the stress wave in tungsten is about 5000m/s, after 0.2µs the peak comes. We can clearly see the period of 0.2µs in the figure. In the theory, the shorter pulse is, the higher of the peak will be.

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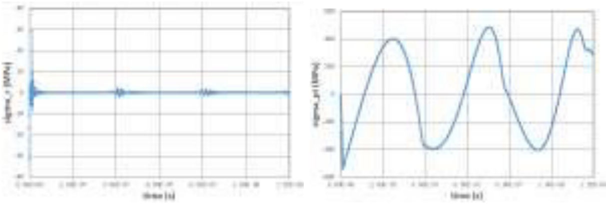

Figure 6: At edge, stress of sphere of sigma r (left) and sigma phi (right) development with time due to 10ns thermal pulse for the sphere model.

Figure 6 shows the stress of sigma r and sigma phi development with time at the edge of sphere. As we can see, due to the boundary is free at edge, the stress at r direction is near zero. But the stress phi will have a period oscillation. However, the value are much smaller than that in the centre.

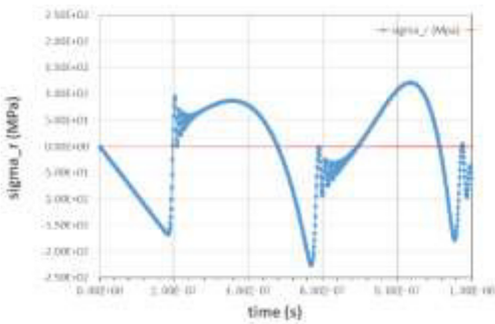

Figure 7: At centre, sigma r development with time due to 1µs thermal pulse for the sphere model.

Besides 10ns pulse, 1µs pulse heating are also studied. Figure 7 shows the results. Since 1µs is longer than 0.2µs of the period, we can see, at 0.2 µs the linear decrease of the stress has an obvious change. However the value is not as great as the 1ns pulse. It will be safe if a 1µs pulse used when only this model considered.

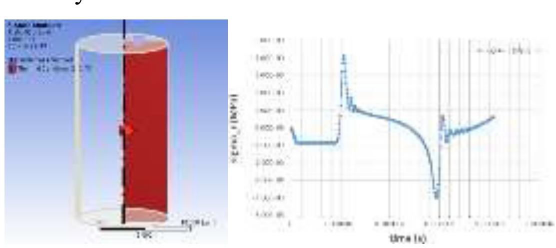

Figure 8: Left is a cylinder model for shock study. Axial constrained and radial free; and temperature is uniform of 200C. Right is the results for 100ns pulse study.

In additional, we also studied the shock in the cylinder. Figure 7 shows the model and the 100ns pulse results at the centre. The diameter of the cylinder is 10mm. It has a similar results as in sphere for first period. Due to the radius is 5mm, the first peak comes at 1µs. It is a reasonable value. However the value of stress is higher than sphere. This can be simply understood that the ratio of surface over volume of cylinder less than that of sphere.

BUCKLING STUDY

Windows are also one of important part of the design of a target. The tungsten target at the downstream end is under serious stress and shock. To place a titanium window at the target end could prevent target material from being spilled out. This study is intended to evaluate its resistance of titanium window to the beam. The window is flat and a round disk, with a diameter of 20mm, constrained at its edge. The peak temperature per pulse at the window will be 70C (PEDD is about 35J/g). Material used for the window is Ti6Al4V. One of problems for the thin-walled structure is buckling.

Table 1: Critical Buckling Temperature for 1st Order Mode

	Thickness(mm)	Critical temperature(C)
1	0.1	10
2	0.25	64.61
3	0.5	256.2
4	1	997.01

Table 1 shows the linear buckling results of critical temperature. As we can see, if working temperature is above 200C, the thickness should be more than 0.5mm for safe. Besides, the nonlinear buckling simulation is also carried out to double check the results shown in figure 9. It is clear at about 230C, the stress will begin increase with a stress of about 120MPa. It is a safe value.

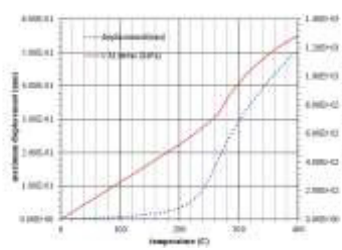

Figure 9: Nonlinear buckling simulation results.

SUMMARY

Thermal load which are driven by the pulsed e-beam, causes rapid dynamic loads in the target which can lead to fracture and failure of it. In this paper, several numerical analyses on Tungsten target stresses are introduced. The dynamic stresses from both of extremely short (10 ns) and nominal (1µs) thermal pulses are studied. Particular attention has also been paid to the buckling of foils.

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