Strip Foil Heating and Stress Analysis

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Carbon foil

- The size of the carbon foil is

  2.6 cm x 3.8 cm

  The thickness is given by $\mu g/cm^2$

  Old foil is 300 $\mu g/cm^2$

  New oil is 400 ~ 600 $\mu g/cm^2$

  (The density of carbon foil is 2 g/cm^3,

  So its thickness is equivalent to 2 ~ 3 μm)

  We use 600 $\mu g/cm^2$ for this analysis.

Carbon properties

- From *The Proton Driver Design Study* (FermiLab-TM-2136) section 11.3, we have following data
- Density $\rho = 2.0$ g/cm^3
- Specific heat $c = 0.165$ cal/g-K = 0.69 J/g-K
- Conductivity $k = 0.057$ cal/cm-K-s = 0.24 w/cm-K
- Emissivity $\varepsilon = 0.80$

- From *graphite properties* by John Jaszczak
- Density $\rho = 2.2$ g/cm^3
- Conductivity $k = 1.60$ w/cm-K
- Bulk modulus $K = 15$ Gpa (irradiated, uncoated)

- From the properties data, we see that our carbon foil is less dense than typical graphite. Hence when calculate the stress we assume less stiffness than typical data.
- Let K = 12 GPa, ν = 0.3, we have

  E = 14.4 GPa

Beam Pulse

Beam energy = 8 GeV
Beam current = 25 mA (8 mA)
Pulse duration = 1 ms (3 ms)
Repeat rate = 1/1.5 Hz
Beam size = 4mmx8mm (Gaussian)

Electron charge *e* = 1.6e-19 C.
Beam pulse has (25e-3)(1e-3) = 25e-6 C.
One beam pulse has
N = 25e-6 / 1.6e-19 = 15.6e13 protons.

Beam Cross Section

The distribution of the beam particles over the cross section is assumed Gaussian

$$P = \frac{N}{2\pi\sigma_x\sigma_y} \; e^{-x^2/2\sigma_x^2} \; e^{-y^2/2\sigma_y^2}$$

From the beam size given, we let

σ_x = 0.2 cm, and σ_y = 0.1 cm.

Energy deposition

$$S = \frac{N}{2\pi\sigma_x\sigma_y}\left|\frac{\mathrm{d}E}{\mathrm{d}z}\right| e^{-x^2/2\sigma_x^2} e^{-y^2/2\sigma_y^2}$$

|d*E*/d*z*| = 1.8 MeV/(g/cm2).

For thickness of 600 μg/cm^2, the energy deposition is (1.8)(600e-6) = 10.8e-4 MeV per particle. The total energy deposition is therefore *N* |d*E*/d*z*| *dz* = (15.6e13)(10.8e-4) = 168e9 MeV = 270e-4 J.

Since an average proton hits the foil 6 times, and two electrons hit foil once, above number should be multiplied by a factor of 8. Total energy deposit is 0.216 J per beam pulse. The maximum energy density is 1.719 J/cm^2 = 2865 J/g.

Thermal and mechanical process

- Thermal process is governed by diffusion, its speed is determined by $k/\rho c = 0.24/(2.0 \times 0.69) = 0.174$ cm^2/s. During the time of 1 ms (beam length), the diffusion length is 0.0132 cm, much smaller than the foil size.
- Mechanical process propagates with speed of sound.

  $V = (E/\rho)^{1/2} = 2558$ m/s. During the time of 1 ms, the mechanical disturbance propagates 255.8 cm, much larger than the foil size.
- Energy deposition can be considered instantaneous when thermal process is concerned, and can be considered static when mechanical process is concerned.

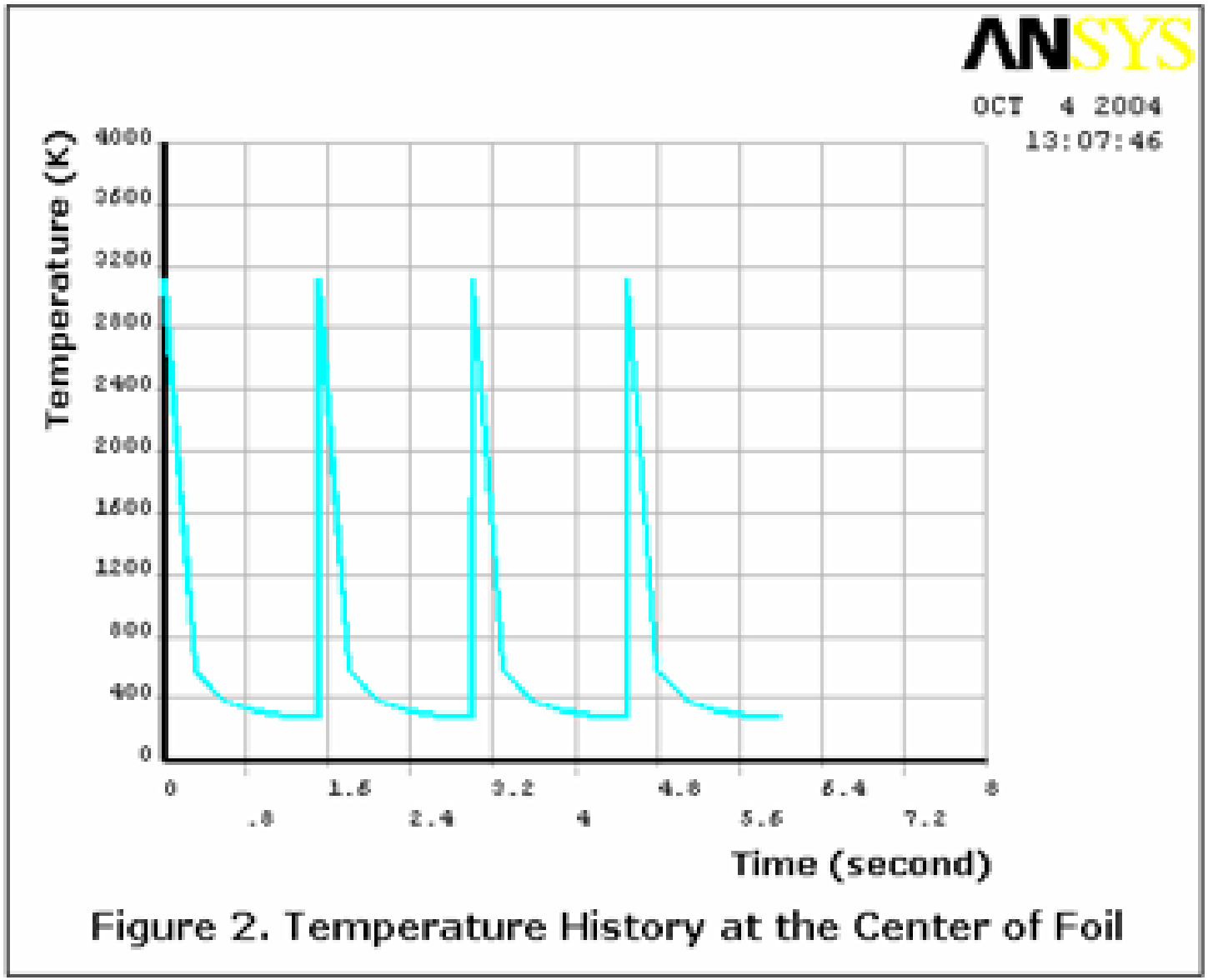

Figure 2. Temperature History at the Center of Foil

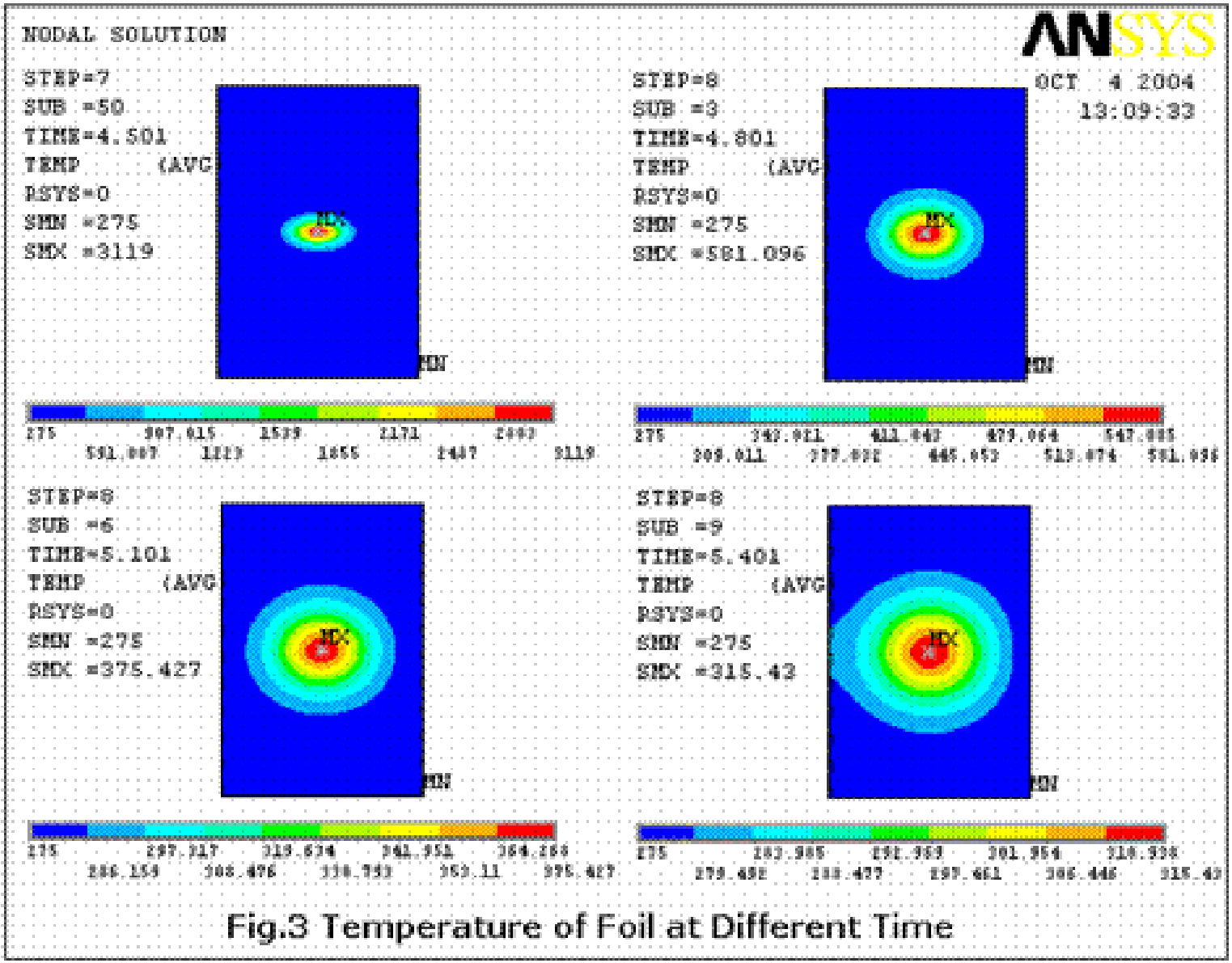

Fig.3 Temperature of Foil at Different Time

Thermal analysis Results

Temperature increase is 1675 K

Assuming initially at 275 K, maximum temperature is 1950 K

There is no temperature accumulation

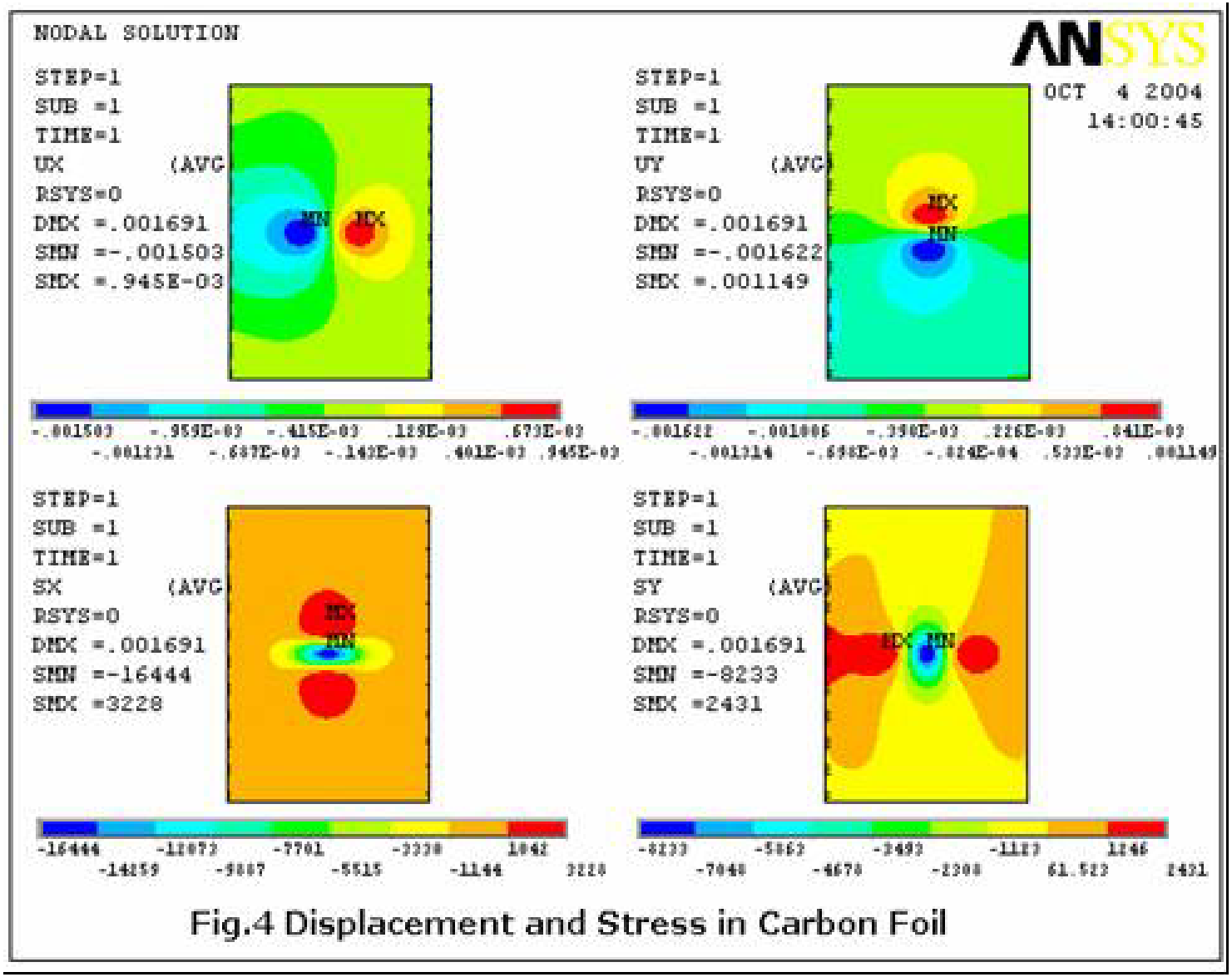

Fig.4 Displacement and Stress in Carbon Foil

Mechanical Analysis Results

Maximum Displacement 0.866e-3 cm
(thickness of foil 0.3e-3 cm)

Maximum stress 9678 N/cm^2 (14033 psi)

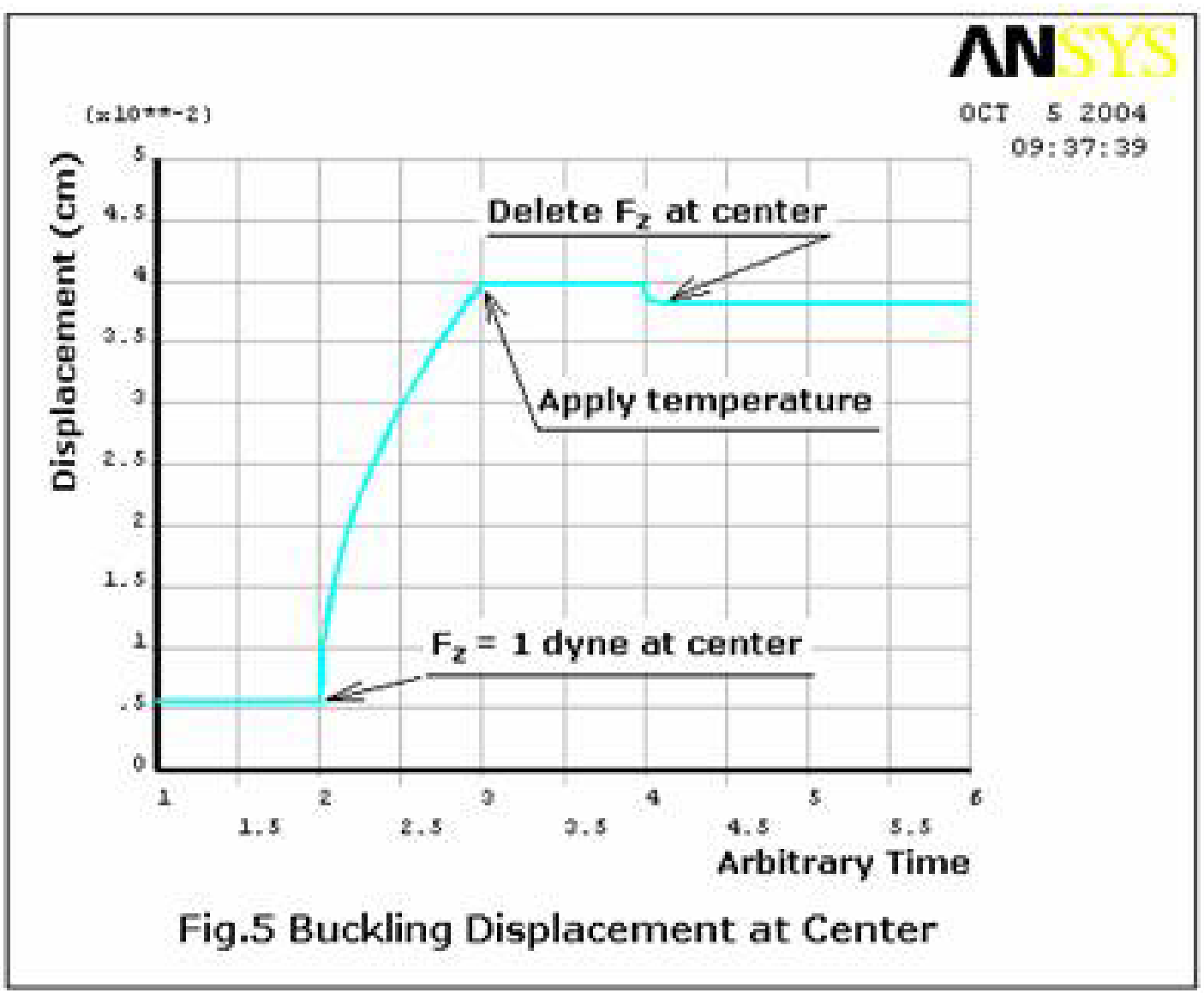

Fig.5 Buckling Displacement at Center

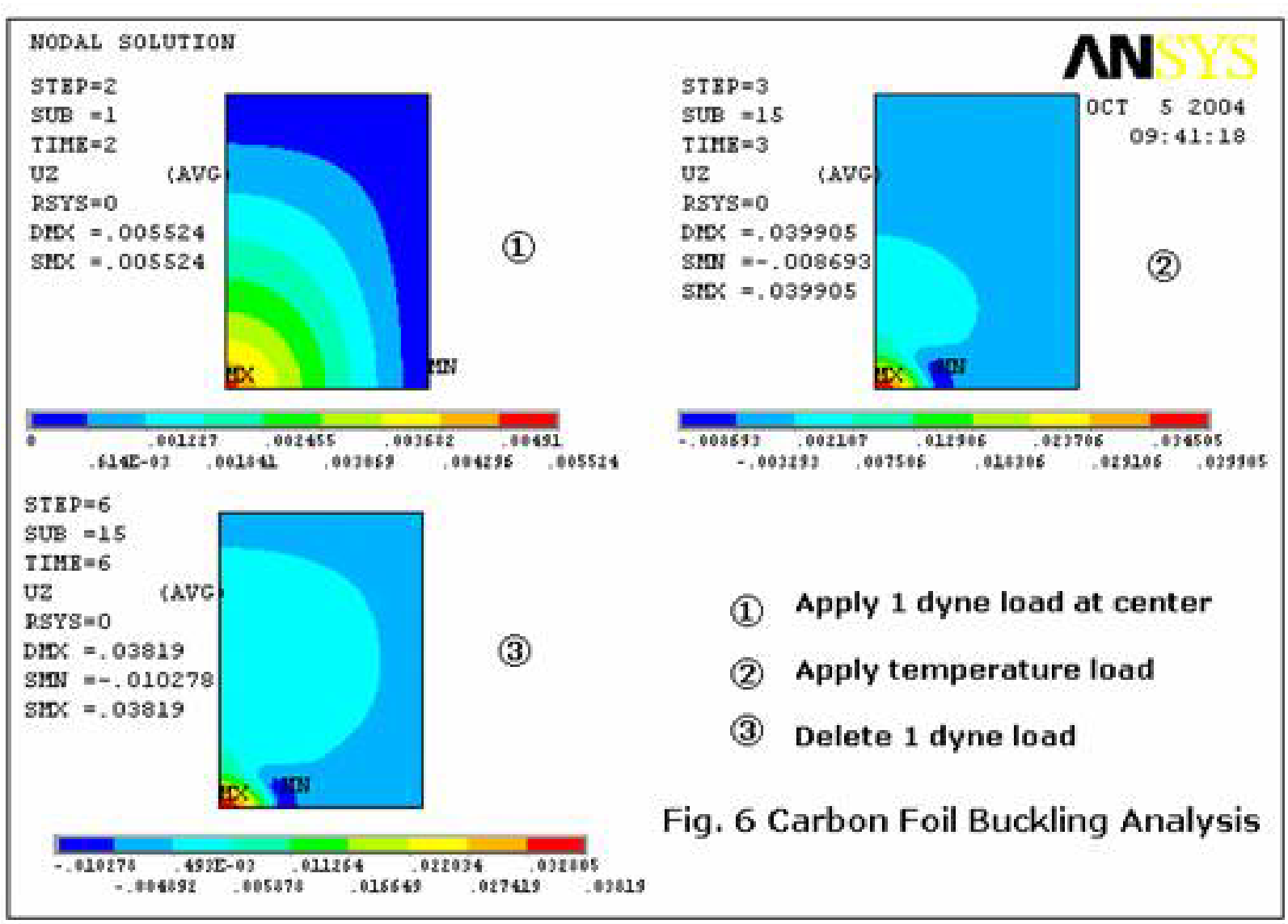

Fig. 6 Carbon Foil Buckling Analysis

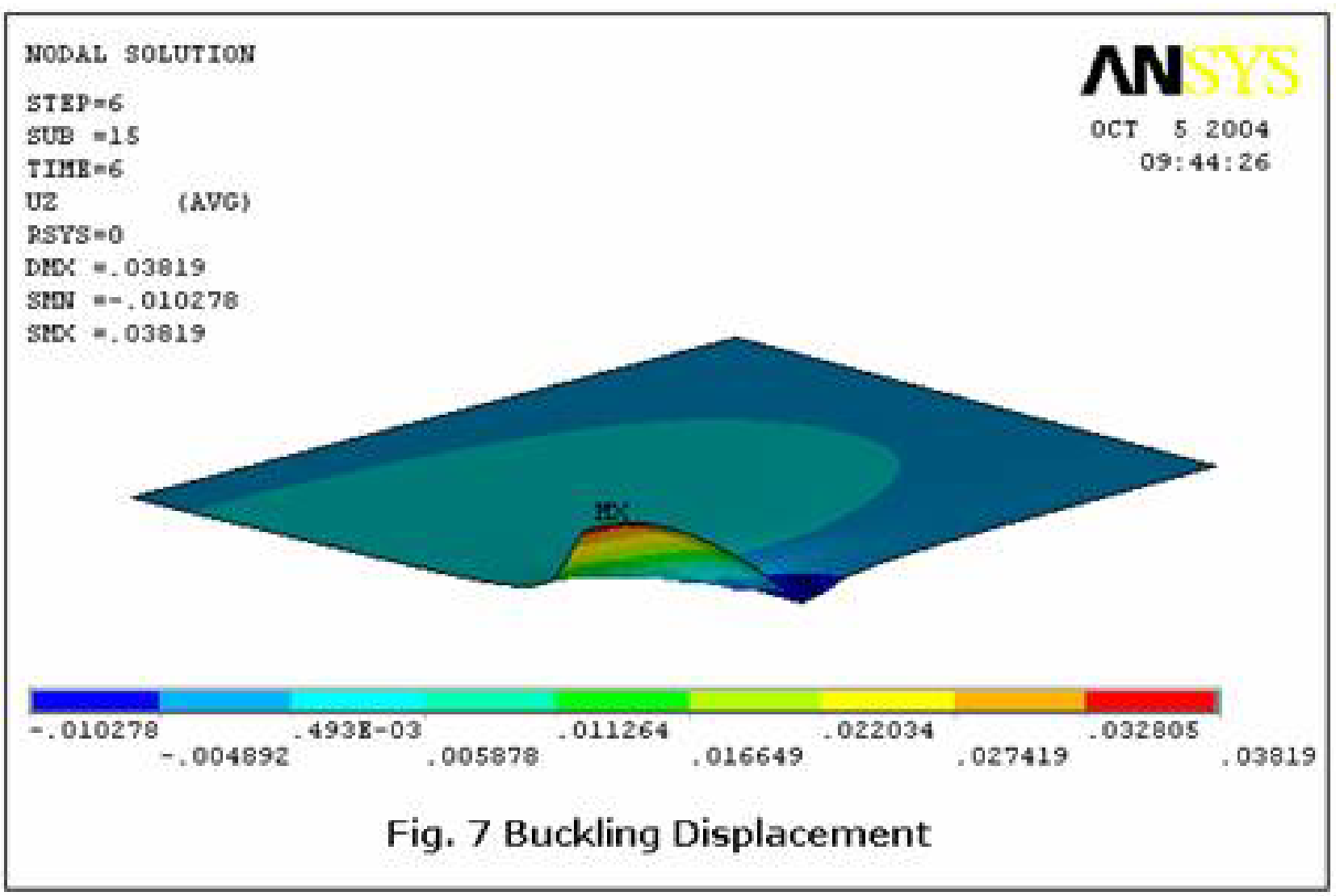

Fig. 7 Buckling Displacement

Buckling Analysis Results

buckling (out-of-plane) displacement is 0.031 cm
Compare with static (in-plane) displacement of 0.866e-3 cm (35 times larger) and the thickness of foil (0.3e-3 cm) (100 times larger)

Conclusion

- 1.5 second is enough for thermal radiation to dissipate the beam heat deposition
- Maximum temperature and stress is determined by energy deposited in one beam pulse
- Maximum temperature increase is 1675K and maximum stress is 9678 N/cm^2
- Buckling will be an important issue. Repeated buckling will damage the foil