A NOTE OF THERMAL ANALYSIS IN SYNCHROTRON RADIATION ACCELERATOR ENGINEERING

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Abstract

Thermal and thermomechanical analysis is one of the key process while designing accelerator components that may subject to synchrotron radiation heating. Even some closed-form solutions are available, and yet as to complex geometry numerical analysis such as finite element method (FEM) is commonly used to obtain the result. However due to its complexity of density distribution of the heat load, implementing such boundary conditions in the finite element method (FEM) model is relatively tedious.
In this report we provide a simplified, practical and more conservative method to apply heat load both for bending magnet and insertion device. In addition, a general purpose synchrotron radiation heating numerical modelling is also introduced, and a simple FEM model with EPU power heat load is also compared

Bending magnet

Gaussian type power distribution

$$q\left[\frac{Kw}{mrad^2}\right] = 5.425E[GeV]B[T]I[mA]\frac{1}{\left(1+\gamma^2\varphi^2\right)^{5/2}}\left(1+\frac{5}{7}\frac{\gamma^2\varphi^2}{\left(1+\gamma^2\varphi^2\right)}\right) \approx 5.425E[GeV]B[T]I[mA]\exp\left(-\frac{\varphi^2}{2\left(\sigma_o/\gamma\right)^2}\right)$$

$$\sigma_0 = \frac{32}{21\sqrt{2\pi}} \approx 0.608$$

Step function power distribution

$$q\left[\frac{Kw}{mrad^2}\right] = 5.425E[GeV]B[T]I[mA](H(\varphi-\frac{\sigma_c}{\gamma}) - H(\varphi+\frac{\sigma_c}{\gamma}))$$

$$\sigma_c = 0.608\sqrt{\frac{\pi}{2}} \approx 0.762$$

Insertion device

Gaussian type power distribution

$$q[\frac{w}{mrad^2}] = 0.0844E^4[GeV]I[A]\frac{L[m]}{\lambda_o^2[m]} f\left(k_x,k_y,\theta_x,\theta_y\right)$$

$$f\left(k_x,k_y,\theta_x,\theta_y\right) = \int_{-\pi}^{\pi}\left[\frac{(k_x^2\cos^2\alpha + k_y^2\sin^2\alpha)}{\left(1+(k_y\sin\alpha-\gamma\theta_x)^2+(k_x\cos\alpha-\gamma\theta_y)^2\right)^3} - \frac{\left[\left(k_y^2-k_x^2\right)\sin 2\alpha - 2k_y\gamma\theta_x\cos\alpha + 2k_x\gamma\theta_y\sin\alpha\right]^2}{\left(1+(k_y\sin\alpha-\gamma\theta_x)^2+(k_x\cos\alpha-\gamma\theta_y)^2\right)^5}\right]d\alpha \approx$$

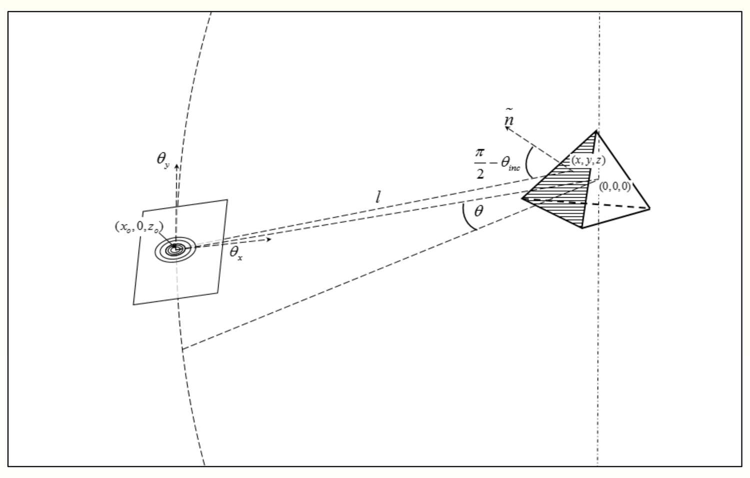
$$\beta = \begin{cases} \dfrac{k_x}{k_y} & \text{when } k_y > k_x \\ \dfrac{k_y}{k_x} & \text{when } k_x > k_y \end{cases}$$

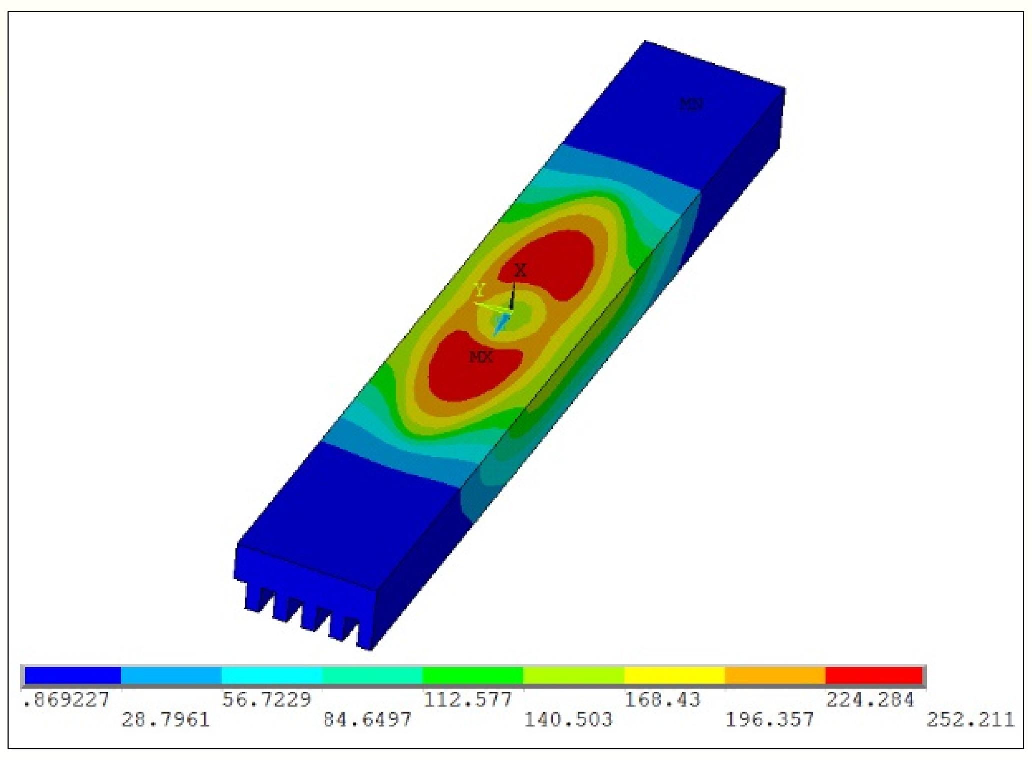
$$\left(k_x\cos^2\theta + k_y\sin^2\theta\right)\exp\left(-\frac{\left(\frac{k_x^2k_y^2}{k_x^2\cos^2\theta+k_y^2\sin^2\theta}\frac{1}{\left(2\beta-\beta^2\right)^2}\left(\sqrt{\frac{\theta_x^2}{\left(\frac{k_y}{\gamma}\right)^2}+\frac{\theta_y^2}{\left(\frac{k_x}{\gamma}\right)^2}}-1\right)\right)^2}{2\sigma_o^2}\right)$$

$$\sigma_c \approx 0.762\frac{(\beta^2+1)}{(\beta+1)}$$

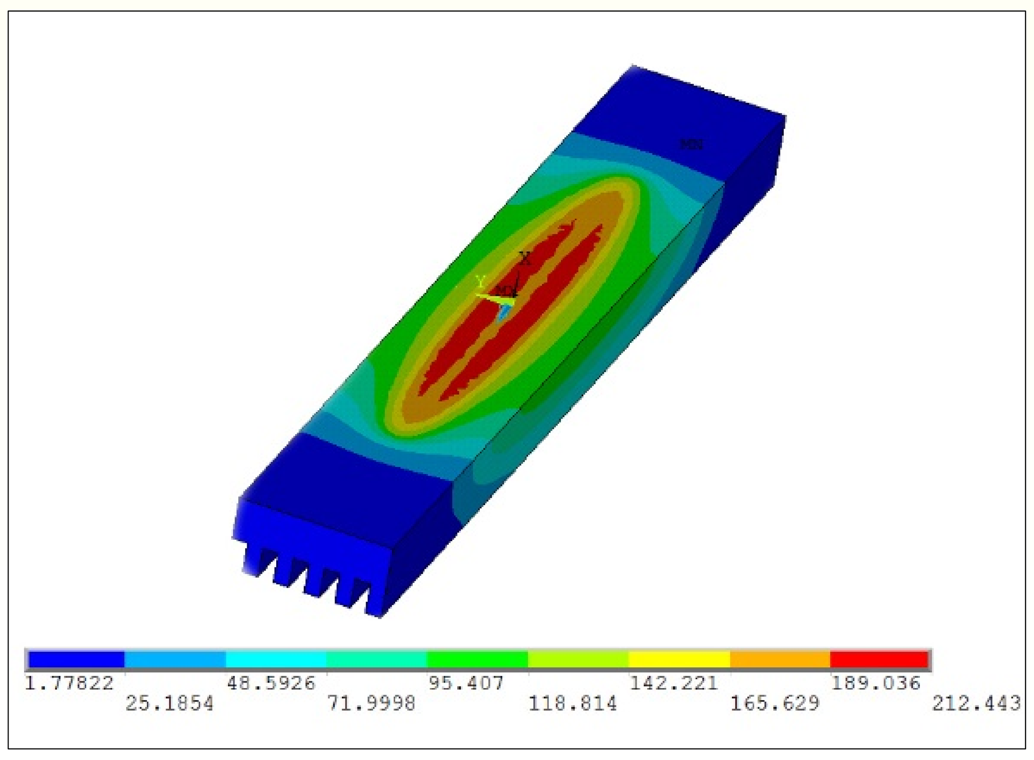
Step function power distribution

$$\text{footprint} = \pi\left(\left(\frac{k_y}{\gamma}+\frac{\sigma_c}{\gamma}\right)\left(\frac{k_x}{\gamma}+\frac{\sigma_c}{\gamma}\right)-\left(\frac{k_y}{\gamma}-\frac{\sigma_c}{\gamma}\right)\left(\frac{k_x}{\gamma}-\frac{\sigma_c}{\gamma}\right)\right) = \frac{2\pi\left(k_x+k_y\right)\sigma_c}{\gamma^2}$$





Step function power temperature contour



Gaussian power temperature contour

Conclusion

A simplified step function power heating is developed both for bending magnet and insertion device. Simplified power distribution is much more efficient to implement for FEM analysis, and yet it provides more conservative temperature result. There are some evidence shows that in some specific geometry, the result might be reversed and it requires further investigations.