Obtaining finite element thermal loads from fluence maps and voxels

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ABSTRACT

In conducting a STOP analysis, it is often required to convert laser fluence maps or voxel maps from an optical analysis into finite element heat loads for thermal and thermoelastic analyses. These fluence maps are usually represented as a rectangular array at optical surfaces. A technique has been developed to convert these maps into surface and volumetric loads on arbitrary 2D and 3D finite element (FE) meshes. For lenses, any number of intermediate maps through the lens thickness are allowed when more resolution is required. Another output format used by optics codes is three dimensional cubes called voxels. Voxel data can also be converted to FE loads. As data checks, the total heat absorbed is reported for each surface and each lens volume and compared to the FE load created. The technique is available in SigFit, a commercially available tool integrating mechanical analysis with optical analysis.

Keywords: STOP analysis, fluence maps, voxels, heat loads, finite elements, optomechanical analysis.

1. INTRODUCTION

In conducting a STOP[1] analysis, it is often required to convert laser fluence maps or voxel maps from an optical analysis into finite element heat loads for thermal and thermoelastic analyses. These maps are usually represented as a rectangular array at optical surfaces. A technique has been developed to convert these maps into surface and volumetric loads on arbitrary 2D and 3D finite element (FE) meshes. For lenses, any number of intermediate maps through the lens thickness are allowed when more resolution is required. Another output format used by optics codes is three dimensional cubes called voxels. Voxel data can also be converted to FE loads. As data checks, the total heat absorbed is reported for each surface and each lens volume and compared to the FE load created. The technique is available in SigFit[2], a commercially available tool integrating mechanical analysis with optical analysis.

Once the thermal loads are created, a heat transfer analysis and subsequent thermoelastic analysis can be run in the FE code. SigFit can then be used on the temperature profile to conduct a thermo-optic (dndT) analysis[3] and write the results to the optics code as an OPD map or user gradient index (GRIN) file. The thermoelastic distortions can then be fit with polynomials for input to the optics code for optical analysis

2. TWO DIMENSION FLUENCE MAP ON MIRRORS

2.1 Surface absorption

The incidence flux is represented as a rectangular array on a mirror surface. The form of flux may vary significantly over the surface as shown in the laser flux on a mirror in Figure 1.

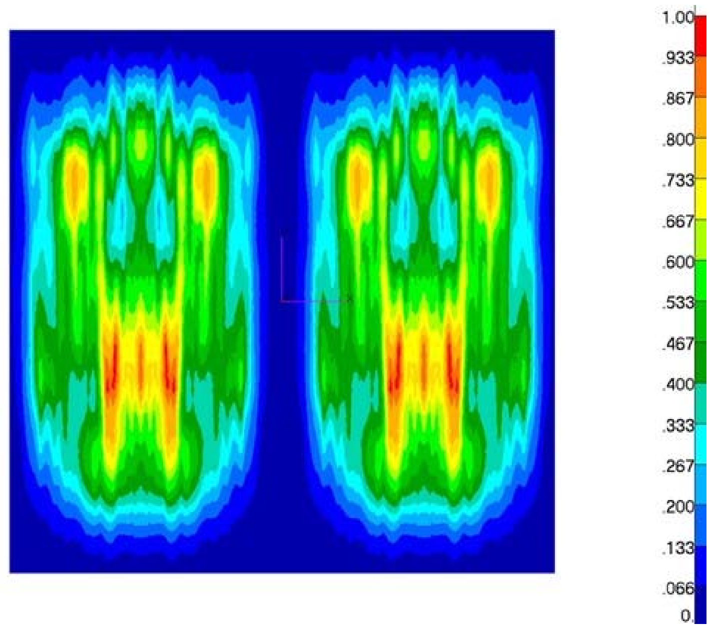

Figure 1: Laser flux on a mirror surface

The flux is represented by a grid array of pixelated data. The absorbed energy (Qj) into the surface at any array cell (j) is the incident flux (Fj) times the surface absorption coefficient (aj) and area of cell (Aj). This absorbed energy must be converted into thermal loads on the finite element model.

$$Q_j = \alpha_j A_j F_j \tag{1}$$

SigFit does a search over the FE model of the surface to find which element (e) contains the array point (j) as in Figure 2. The centroid of array point (j) is converted to element (e) isoparametric coordinates. Then the energy in this array cell (j) is distributed to element (e) node (i) using shape functions as shown in equation 2.

$$S_i = N_i^{(e)}(\xi_1, \xi_2) Q_j \tag{2}$$

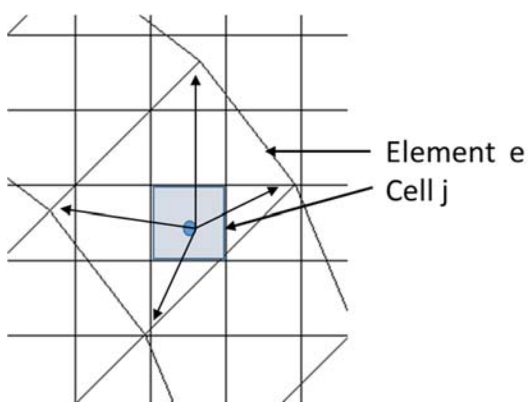

Figure 2: Surface flux distributed to FE nodes

The procedure steps through every cell in the fluence array. Nodal loads are summed for a heat transfer analysis and output as thermal loads to the FE model. As a data check, the total absorbed flux (Qtot) is compared to total thermal load

(Stot). If any cell is outside of the FE model, the user can choose to report it as energy lost, or assign it to the surface load by a closest node technique.

3. TWO DIMENSION FLUENCE MAP ON LENSES

3.1 Surface absorption

Given fluence maps for the entrance and exit surface, the entrance and exit surface's absorption is calculated using the techniques in the previous section. The volumetric absorption is described in the next section.

3.2 Volumetric absorption

The energy transmitted (Tj) through an entrance surface cell (j) is defined by the transmission coefficient (tj).

$$T_j = \tau_j A_j F_j \tag{3}$$

SigFit creates a path through the lens from entrance cell (j) to its corresponding exit surface (j). From a user specified number of steps, the path is broken into equal increments. The energy associated with any increment (xp) is the current energy step Q(xp) given as

$$Q_{xp} = T_{xp-1} \alpha \Delta V_{xp} \tag{4}$$

Where T_{xp-1} is the energy transmitted by previous step, α is the volumetric absorptivity, and ΔV is the volume associated with this step. A search is conducted over the solid FE elements in the lens to find the element containing point xp. The energy absorbed is converted to nodal heat loads by using shape functions for the enclosing element as shown in Figure 3.

$$S_i = N_i^{(e)}(\xi_1, \xi_2, \xi_3) Q_j^{(xp)} \tag{5}$$

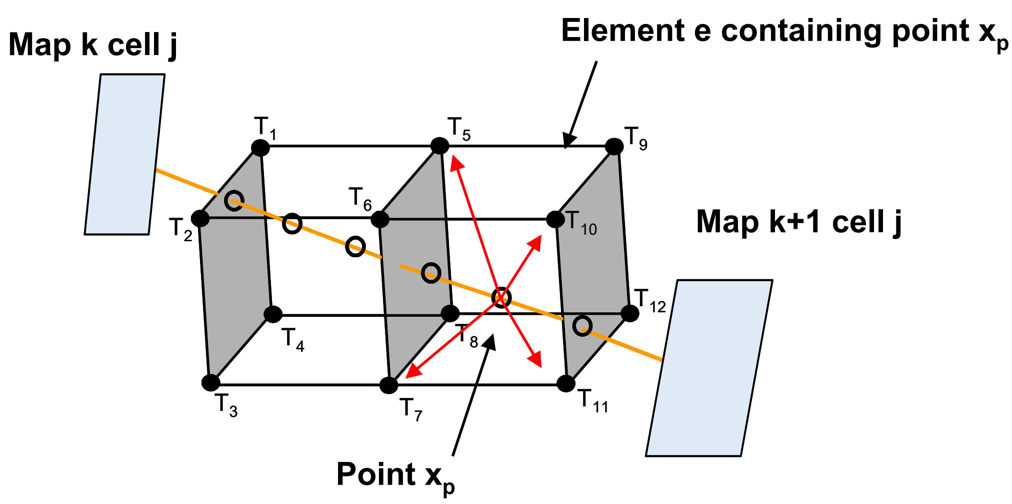

Figure 3: volumetric absorption

Again, an energy balance check is reported, comparing incident energy to energy absorbed, transmitted, reflected, and finite element heat loads.

4. VOXEL LOADS

4.1 Large voxels

Voxels are a three dimensional array of rectangular boxes which contain the energy absorbed from all sources. If the voxels are larger than the typical FE mesh, a search is conducted to find all nodes (i) contained in a voxel in Figure 4. The energy (Uj) in voxel (j) is distributed to each FE node (i) enclosed in it according to the FE volume (Vi) associated with node (i).

$$Vsum = \sum_{i=nodesenclosed} V_i \tag{6}$$

$$S_i = {U_j V_i}/{Vsum} \tag{7}$$

Figure 4: Large voxel containing FE nodes

If there are no FE nodes contained in a voxel with non-zero energy, the user may select to have that energy distributed to the N closest nodes, where N is user selectable. These non-zero cells are reported in the output.

4.2 Small voxels

If the voxels are small relative to the FE mesh, the voxel energy Uj is distributed to the nodes of the enclosing FE element using shape functions as shown in figure 5. In the following equation ξ are element (e) parametric coordinates of cell (j) centroid.

$$S_i = N_i^{(e)}(\xi_1, \xi_2, \xi_3)U_j \tag{8}$$

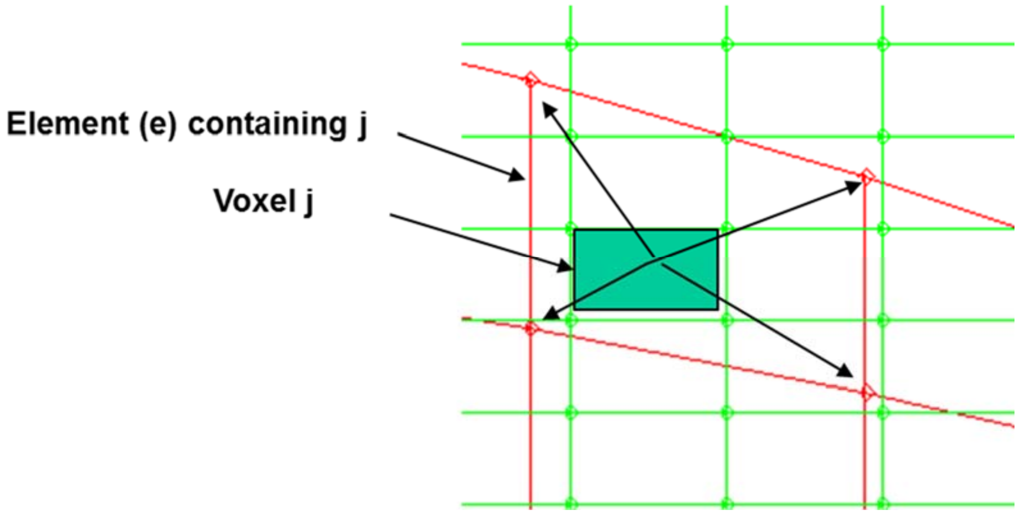

Figure 5: Small voxel energy distributed to nodes

Again, if the voxel is not contained in any FE element, the user may select to distribute using closest node technique. As in all the above techniques an energy balance is reported.

5. STOP ANALYSIS

5.1 Thermo-optic analysis

With laser fluence maps or voxel loads converted to FE heat loads, a heat transfer analysis can be conducted to get temperatures throughout the FE model. The effect of index change due to temperature can be evaluated in SigFit as shown in Figure 6. The user may select an approximate, but fast technique, to create optical path difference (OPD) maps for each lens. In more accurate technique, SigFit will create a user gradient index (GRIN) lens DLL for calculating the index within the optics program ray trace.

5.2 Thermoelastic analysis

From the temperature distribution, a FE thermoelastic analysis predicts surface distortions which SigFit can process and pass to an optics program, typically as Zernike polynomials and decenters and tilts. The FE thermoelastic analysis also calculates stress within a lens. SigFit can read the stresses and write OPD maps representing index change due to stress[4] to the optics code.

The flow chart for STOP analysis is shown in Figure 6 and described in References 5 through 7.

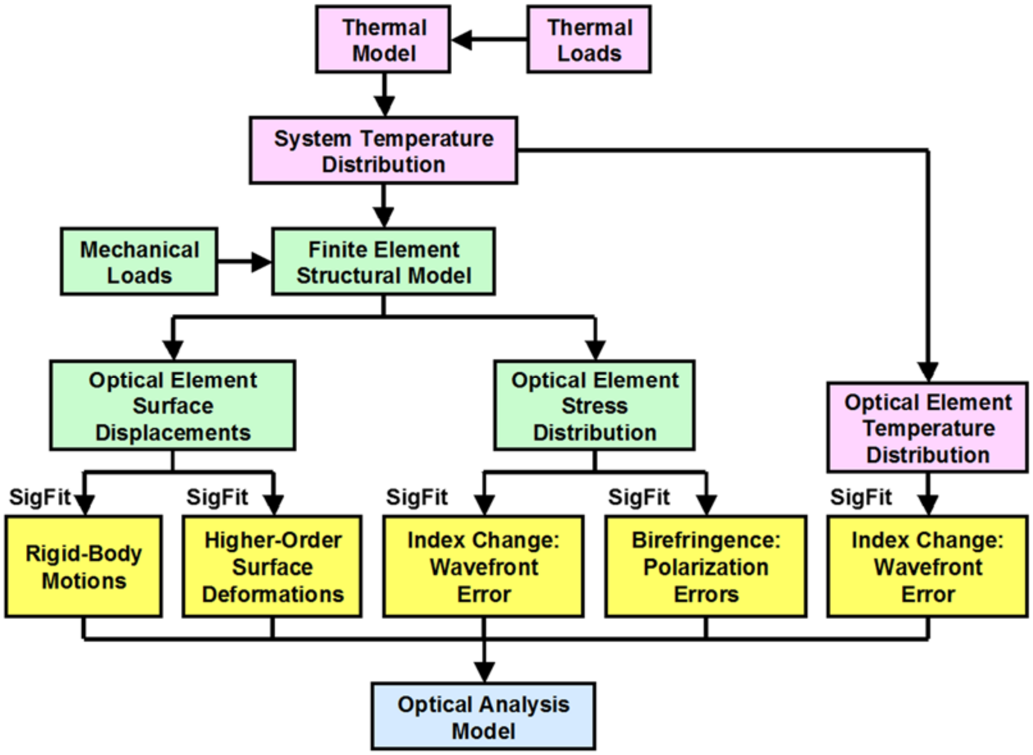

Figure 6: Stop analysis flow chart

6. CONCLUSIONS

A technique has been presented to convert laser loads in the form of fluence arrays or voxels into finite element heat transfer loads. This allows for subsequent heat transfer analysis and thermoelastic analysis which can be used in a STOP analysis.

REFERENCES

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