ANALYSIS OF THERMOINELASTIC DISSIPATIVE STRUCTURES

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SUMMARY

A general theory and a method of analysis for thermoinelastic structures were presented by T.J. Chung (SMiRT-2 Paper L 4/2). In the present paper, a significant extension is made to account for finite deformation of the thermoviscoplastic structures. Effects of energy dissipation due to a highly nonlinear character of the material behavior are thoroughly investigated.

The central question here is whether all nonlinear problems or discontinuous functions can be viewed as linear or continuous at an infinitesimal or incremental quantity of temporal and spatial domains. Let us consider a structure subjected to any arbitrary loading, and let us picture the material being strained within an infinitesimal time frame, say, a small fraction of a second. Although the current state of stress and strain is inherited from the past histories of nonlinearities, what happens during this infinitesimal time domain can indeed be assumed to be linear. If we can propose a free energy functional valid for this small time increment, not for the entire time domain of investigation, then we are able to derive an incremental constitutive equation by applying the first and second laws of thermodynamics. On this premise, the incremental free energy functional is constructed by a simple superposition of all the sources of energies, such as due to elastic strain, plastic strain, temperature, and viscous strain rate. This leads to an incremental linearized constitutive relation which depends on the past histories and which characterizes the future performance. The incremental stress, equation of motion, and heat conduction equations are derived in the form,

$$\mathrm{d}\sigma^{ij} = E^{ijkl}\,\mathrm{d}\gamma_{kl} + \overset{*}{E}^{ijkl}\,\mathrm{d}\gamma_{kl} + \sum_{r=1}^{n} \xi^{ijkl}_{(r)}\,\mathrm{d}\overset{(r)}{\alpha}_{kl} - B^{ij}\,\mathrm{d}T - \overset{*}{B}^{ij}\,\mathrm{d}T$$

$$[\sigma^{ij}(\delta^m_i + u^m_{|i})],_j + \rho_0 f_m - \rho_0 \ddot{u}_m = 0$$

$$c\dot{T} - q^i_{|i} - \rho h - D + T_0\{(B^{ij} + \overset{*}{B}^{ij} + \overset{*}{\beta}^{ij})\,\dot{\gamma}_{ij} + (\tilde{B} + \tilde{\beta})\,\dot{T} + \sum_{r=1}^{n} B^{ij}_{(r)}\,\overset{(r)}{\dot{\alpha}}_{ij}\} = 0$$

with the strain tensor containing the nonlinear term linearized within a small time increment. The dissipation D is a function of nonlinear stress-strain histories.

To demonstrate the present formulation, an axisymmetric container vessel subjected to internal pressure and high temperature is analyzed via finite element discretization. As a result of the numerical analysis, it is found that dissipation of energy plays an important role. It is concluded that high rate of loading either by pressure or temperature results in large dissipation. Effects of material constants, such as the yield stress, plastic modulus, and relaxation time, are also found significant in dissipation of energy. For low yield stress, small plastic modulus, and large relaxation time, dissipation tends to increase. Finally, it is observed that the large finite deformation also gives rise to a considerable increase in dissipation.