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HARMONIC MODEL FOR NONLINEAR THERMO-MECHANICAL ANALYSIS OF HOT MILL ROLLS

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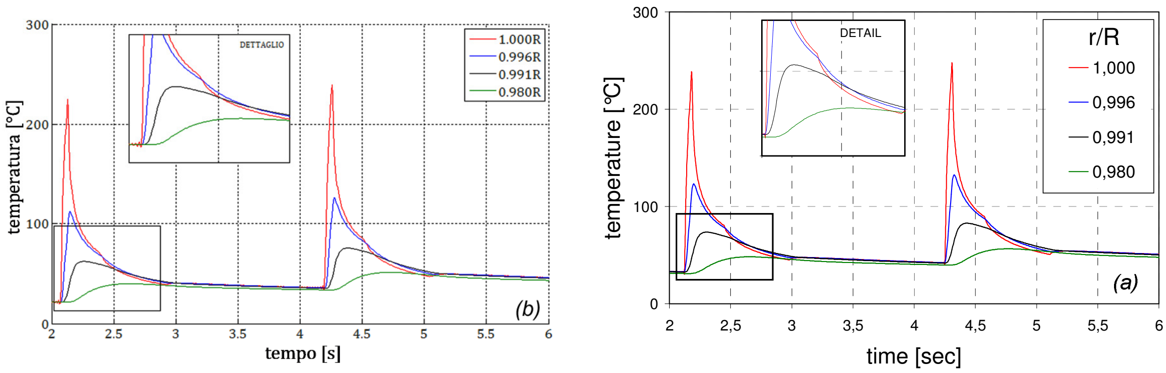
The work deals with the non-linear thermal analysis and the non-linear stress analysis, in static or transient regime, of a work roll of a hot rolling mill considered as a 2D axial-symmetrical structure subjected to non-axial symmetrical temperature field and forces.

Semi-analytical methods for finite element analysis of axisymmetric structures loaded non-axisymmetrically has been developed more than 50 years ago. This approach generally permits a three-dimensional model to be reduced to a plane problem whose solution is obtained by superimposing a finite number of component analyses, the first *n* terms of Fourier series, [1, 2, 3, 4, 5]. In the particular case of a work roll, the problem is considered a 2D plane strain one, due to the length of the roll, thus obtaining a very simple and fast 1D harmonic model.

Even if commercial FEM codes often include harmonic finite elements, their usage is generally limited due to practical difficulties related to Fourier series decomposition or to imposing certain boundary conditions. Few works are reported dealing with engineering practical application.

An example is presented in detail: work rolls in hot rolling mills usually experience cyclic thermal and mechanical stresses [6]. Thermal stresses are produced by non-uniform temperature field induced by strip heating followed by water jet cooling, while mechanical stresses are produced by rolling pressures and contact stresses with back-up rolls. Thermal stresses are usually as great as mechanical stresses, if not even larger, and are responsible for both elastic and plastic deformations, as well as for surface damage mechanisms (as wear, thermal fatigue, 'spalling').

Two finite element models were developed: the first one, written in Matlab language, is based on an original formulation of an harmonic 1D finite element ; the second one is based on a standard 2D approach using a commercial Code (ANSYS) [7, 8, 9]. ANSYS model proved to be reliable and accurate, the main drawback being the extremely long computer time in the case of transient analysis due to the fine finite element mesh required by the very high gradient of temperature and stresses in the vicinity of contact region. In general, using harmonic model for linear analysis, uncoupled small algebraic linear systems are obtained, one system for each term of Fourier series. Convection “slightly” couples the linear systems but the computer time is not practically influenced. Because of the plasticity, the stress analysis becomes non-linear and an iterative process is performed at each time step.



a) b)

Fig. 1. Temperature time history for points at different radial depths, along the same angular position. (a) plane Ansys model and (b) harmonic FE model.

However tacking into account the very localized plastic zone, even in this case the computer time does not increase too much. Thermal and elastic material properties were considered variable with temperature. Detailed results are presented, the two finite element models give quite identical results, figure 1.

The main goal was to obtain a numerical approach to perform a very fast and reliable transient non-linear analysis in order to be able to run numerous load cases (different strip thickness, different materials, different angular velocities etc.). The program written by authors proved to be accurate enough and extremely fast.

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