Summary Sliding systems with frictional heating exhibit thermoelastic instability (TEI) when the sliding speed exceeds the critical value. The phenomenon is known to have profound practical meaning in frictional clutches and brakes. It is well defined in terms of the theory of stability with the classical perturbation approach being commonly used. While the perturbation analysis determines stability limits, the recent interests move towards exploration of the unstable process. This is motivated by the fact that many frictional brakes and clutches operate instantaneously in the unstable regime. The solution of the transient unstable process depends on both the initial perturbation of the thermoelastic field and the potential interaction with an underlying non-homogeneous process. The role of those two factors is shown in a clear mathematical form and their practical meaning illustrated by practical examples. The problem is solved using semi-discretization by finite elements and then modal analysis of the resulting transient non-homogeneous problem.

INTRODUCTION

In a sliding system, the distribution of contact pressure is affected by thermal deformations of its components. Since the frictional heat flux is proportional to the pressure, the pressure affects in turn the temperature distribution and thereby the thermal deformations. This fully coupled thermomechanical system exhibits instability if the sliding speed exceeds the critical value [1,2]. The phenomenon, known as frictionally excited Thermoelastic Instability (TEI), has a profound practical meaning in frictional brakes, clutches, as well as in other sliding systems with frictional heating. It leads to the local contact concentrations that manifest themselves by the known hot spots on friction surfaces [1,3,4].

The phenomenon is well-defined in terms of the theory of stability with a classical perturbation approach being commonly used (e.g.,[2]). While the perturbation analysis allows us to determine the stability limit, the recent interests move towards exploration of unstable behavior [4,5]. This is motivated by practical reasons, namely by the fact that many common frictional brakes and clutches operate instantaneously at speeds exceeding the critical speed for TEI, i.e. in the unstable regime [4]. Exploration of the transient thermoelastic process to determine instantaneous temperatures and thermal deformations occurring in these conditions is therefore of great interest.

FORMULATION OF THE PROBLEM

A linear model of the thermoelastic process in a brake or a clutch can usually be adopted for the first stage of its operation, when full contact, without separation, occurs. In the thermoelastic process, an underlying process, which corresponds to the nominal contact conditions, and an overimposed perturbed process can be distinguished. Stability of a linear system does not depend on the underlying process and, consequently, this process is typically ignored in the stability analysis. Further, stability is determined by the growth rate of the perturbation, which can be evaluated without quantitative determination of the perturbation itself. Consequently, neither the underlying process nor the magnitude of the perturbation is typically considered in the stability analysis [2]. By contrast, in this study of the transient behavior of the unstable system quantitative solutions are sought. For this purpose the initial perturbation has to be quantified [4] and the underlying process included. Note that the presence of a meaningful initial perturbation in the thermoelastic field, conveniently assumed in the stability analysis, seems to be questionable in many practical situations. In fact, severe hot spots were detected after a single application of a brake or a clutch with practically uniform initial temperatures, as reported in [3] and [4]. These observations indicate that factors other than the initial perturbation of the thermoelastic field trigger the unstable process. The underlying process seems to play the major role by producing thermoelastic field with components consistent with the unstable modes [4]. This important problem has not yet been addressed in the literature.

METHOD OF ANALYSIS AND RESULTS

A general case of a sliding system composed of two or more solids with frictional heat generation at the contact interfaces is considered. The mechanical part of the problem is treated as a quasistatic elastic contact problem with thermal deformation. The transient character of the problem is attributed to the thermal part of the problem. The stage of the operation of the sliding system during which full contact occurs, without separation, is considered. The finite element method is used for spatial discretization of both the elastic and the thermal parts of the problem. This leads to a semi-discrete problem represented by a system of ordinary differential equations. The system is non-homogeneous, with right-side vector representing the underlying process. The problem is transferred to modal coordinates, with the part of
the solution which corresponds to the initial perturbation and that which represents the underlying process separated. The eigenvalue problem to be solved has a large size in most practical applications. Many practical systems like multidisk clutches and brakes exhibit cyclic symmetry. This property results in a circulant matrix of the system. Eigenvalue problem with a circulant matrix can be decomposed into a collection of much smaller problems and this fact is exploited in the solution. In the system transformed to the modal coordinates, the dominant modes in both parts of the solution (homogeneous and non-homogeneous) are easily be extracted and dimensionality of the problem is significantly reduced.

A meaningful industrial example, when the unstable modes are triggered by the underlying process rather than by the initial perturbation, is demonstrated.

References