On the Formulation of a New Frictional Time Integration Scheme for Large Slip Contact Problems

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Abstract

In this paper a new frictional time integration algorithm suitable for large slip multi-body frictional contact problems is presented. The algorithm is introduced within the simple context of a model problem: the sliding motion of a particle onto a rough surface. Time integration of frictional traction is performed by introducing a new slip path parametrization, which is defined independently of the local surface finite element parametrization used in the spatial triangularization. The key point of the algorithm is that now, in presence of large slips, problems associated with slip motions such that a full incremental slip path is not within a single surface element, are completed bypassed. Remarkably, the algorithm is defined on the solely basis of the unit outward normal field to the surface without any appeal to the underlying local surface finite element triangularization. Geometrically, the assumed slip path can be viewed as an approximation to the geodesic passing through the initial and final points of each incremental slip path. The algorithm is amenable to exact linearization and asymptotic quadratic rate of convergence can be achieved within a Newton-Raphson iterative solution scheme. The algorithm can easily be extended to large slip multi-body frictional contact problems, involving finite strains.

1. Motivation and Goals.

Frictional behavior is usually characterized by the local parametrization induced by the Finite Element (FE) triangularization of the contact surfaces. Within a FE context the isoparametric map arises naturally as the local parametrization to be used. Due to the local character of the parametrization, a frictional time integration based on this local surface parametrization becomes useless when the incremental slip path involves several surface elements, i.e. when it is not within the domain of the local parametrization of a single surface element of the finite element triangularization.

These situations have usually been resolved by a projection of the slip path over an extrapolated surface of a single surface element, defined through an extended parametrization domain. This procedure allows to use a single local parametrization (within an extended domain) where a slip path belongs to different surface elements, each one described with a local parametrization. Such procedures, although usually not addressed in the literature, can be considered as a standard practice in several computer codes as DYNA or FEAP, for example.

Some of the drawbacks of these projection procedures are the following:

i. The projected slip path amounts to find a projection lying outside the limits of the local parametrization domain. Note that, the orientation preserving map induced by the local parametrization, is guaranteed to exist only within the underlying domain. Then situations may arise in which the projection points are located in areas with negative or zero jacobian, leading to a useless algorithm.

ii. The slip amount is one of the main parameters for the characterization of wear phenomena in multi-body frictional wear contact problems. Projection of slip path can lead to an important underestimation of the slip amount, and hence, to an underestimation of frictional traction, frictional dissipation and wear estimate.

The above considerations have motivated the need to get a new frictional time integration algorithm suitable for large slip multi-body frictional contact problems. This new algorithm must be equipped with the following features:

i. Slip path projection-based procedures must be avoided, due to the drawbacks mentioned above.

ii. Use of local surface elements parametrization must be avoided.

iii. A new slip path parametrization suitable for large slips must be introduced.
iv. The new frictional time integration algorithm must be amenable to an exact linearization, to preserve quadratic asymptotic rate of convergence typical of a Newton-Raphson solution scheme.

With these considerations in mind, a new algorithm for the time integration of frictional traction has been proposed by Agelet de Saracibar [1997]. To introduce the main idea of the new algorithm it suffices to consider a simple model problem: the sliding motion of a particle onto a rough surface. The extension of the algorithm to general fully nonlinear multi-body frictional contact problems is straightforward, see Agelet de Saracibar [1997] for details.

2. A New Frictional Time Integration Algorithm.

The numerical analysis of frictional contact problems, using regularization techniques, leads to a constrained evolution problem analogous to the problem of plasticity. Within the context of product formula algorithms, a frictional operator split of the constrained evolution problem can be introduced by means of a trial state (Problem 1), defined by freezing the irreversible (plastic) slip response, followed by a return mapping algorithm (Problem 2). Time integration of the unconstrained evolution equations of Problem 1 involves the computation of the slip amount.

The key point of the new frictional time integration lies in the way in which Problem 1 is integrated and the slip amount is computed. The goal is to be able to compute the slip amount within a typical time interval, in terms of just the current placement of the particle and the unit outward normal to the surface at the beginning and the end of the time interval, avoiding to use the local surface parametrization. This integration is performed by building an assumed slip path, using an Hermitian interpolation function, defined locally in terms of the current placement of the particle and the unit outward normal to the surface at the beginning and at the end of the time step. Geometrically, this assumed slip path can be viewed as a second order approximation to the geodesic defined by these two points and their unit normals to the surface. A step-by-step description of the slip path parametrization and the incremental slip amount computation within a typical subinterval is described in Agelet de Saracibar [1997]. Furthermore, the Lie derivative, along the flow induced by the slip velocity, of the frictional tangent traction is integrated by means of a shifter or orthogonal parallel transport operator along the assumed slip path. On the other hand, integration of the constrained evolution equations defining Problem 2 is performed by a straightforward application of a frictional return mapping algorithm. A step-by-step description of the new frictional time integration algorithm is given in Agelet de Saracibar [1997].


The algorithm outlined in the preceding sections is illustrated below in a 3D numerical simulation: the deep-drawing process of a square cup. The goals are to show the performance of the new frictional contact time integration algorithm at large slips and finite deformations and to demonstrate the robustness of the overall finite element formulation. The calculations are performed with an enhanced version of the finite element program FEAP developed by R.L. Taylor and J.C. Simo.

(A) Square cup deep drawing. This example is taken from a series of benchmark test proposed at the International Conference on Numerical Simulation of 3-D Sheet Metal Forming Processes, NUMISHEET'93, August 31-September 2, Tokyo, Japan. In this example, an initially flat sheet is pressed against a die by means of a blankholder. Then a punch is applied on the top of the sheet to produce the final part. During the deep drawing process, the sheet is not clamped at the edges, the frictional sliding movement of the sheet between the die and the blankholder is allowed. The amount of the sliding movement will depends of the frictional conditions at the interfaces and the blank holder pressure.

The analysis was performed in a Silicon Graphics Power Challenge L Workstation and it was accomplished in 14 h 26 min CPU time. The evolution of the Euclidean norm of the residual at four typical time steps shows a quadratic rate of convergence.

Figure 3.1 shows the evolution of the draw-in values at the corner and at the mid-edges along with the final shape of the sheet for a punch stroke of 40 mm. The final computed draw-in values at the corner and at the mid-edges for a punch stroke of 40 mm compares very well with the average of the experimental
and numerical results submitted for the NUMISHEET'93 benchmark test.

Figure 3.1 Square Cup Deep Drawing. Evolution of the draw-in at the corner (DD) and at the mid-edges (DX and DY) along with final shape of the sheet for a punch stroke of 40 mm.

Figures 3.2 and 3.3 show, respectively, the contact pressure and frictional dissipation distributions at the top and the bottom of the sheet, respectively, for different punch strokes of 10, 20, 30 and 40 mm.

Figure 3.2 Square Cup Deep Drawing. Contact pressure distribution at the top side (left) and bottom side (right) of the sheet: (a) Step=40, Punch stroke=10 mm; (b) Step=80, Punch stroke=20 mm; (c) Step=120, Punch stroke=30 mm; (d) Step=160, Punch stroke=40 mm.

A new frictional time integration algorithm, suitable for large slip frictional contact problems at finite deformations has been presented. The main aspects of the algorithm can be introduced within the context of a simple model problem: the sliding motion of a particle into a fixed surface. The extension to a general large multi-body problem at finite deformations can be performed in a straightforward manner.

The key point of the algorithm lies in the parametrization of the incremental assumed slip path as an approximation to a geodesic curve. Remarkably, this parametrization is defined, only in terms of the initial and final position of the particle and the unit normals to the surface at these points, without using the underlying local surface parametrization. This fact allows to deal with large slip situations in a trivial manner.

The algorithm is amenable to exact linearization getting an asymptotic quadratic rate of convergence when used within a Newton-Raphson solution scheme. The good performance of the algorithm has been shown in a numerical simulation.

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