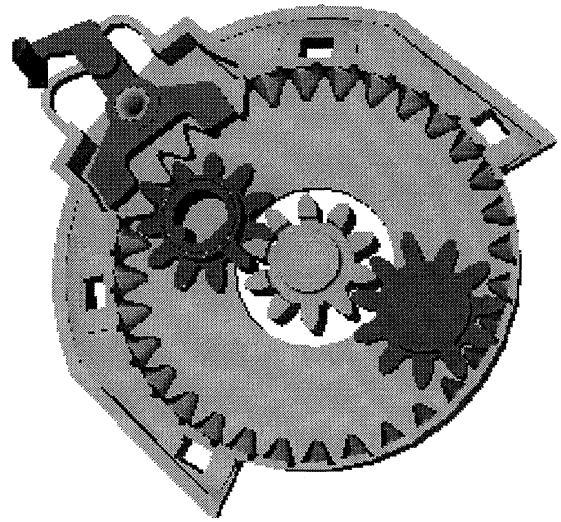
Developments in Penalty Based Analytical Contact Forces



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ABSTRACT

One of the most challenging problems in multibody dynamics is the definition and generation of forces resulting from physical contact. Several methods have been developed to account for various levels of usability and functionality. This paper provides a technical review of the penalty based contact detection and force generation developed by Sam McDonald of Mechanical Dynamics. Furthermore, penalty-based contact and the collision method included in most commercial dynamics software are compared. An illustrative case is provided for applications of the penalty-based method in various industries. Finally, a description of the work in making the current contact functionality is provided.

FUNCTIONAL OVERVIEW

The penalty-based contact is implemented using macros, general force statements and subroutines.

These macros make definition of the forces relatively simple, leaving the calculations to the subroutines. The subroutines are modularized to take advantage of certain algorithms that are redundant for different types of contacts. The basic format consists of a routine which calculates the geometric information, and a routine to determine the force normal magnitude and the stick-slip friction magnitude and direction.

The parameters required to pass to the force routine are detailed in the 1985 ADAMS users conference paper Three-Dimensional Surface Contact . What follows is a sample of the calculations needed to determine the contact location, amount of inter-penetration, and surface normal for a simple circle to circle contact:

```
DIST = dsqrt (x^2+y^2)
CNORM(1) = dx/DIST
CNORM(2) = dy/DIST
CNORM(3) = 0.0d0
conpos(1) = -cnorm(1) *(radius_I)
conpos(2) = -cnorm(2) *(radius_I)
conpos(3) = 0.0d0
IMP(1) = DIST - RADIUS_I
IMP(2) = RADIUS_J
```

The penalty-based contact is implemented using force functions through associated subroutines that are linked into the dynamics code. There are three basic modules for the contact methodology. The first module is the dynamics code that provides the required state variables such as relative location and velocities of the parts corresponding to the contact pair. The second module is a treatment of the contact surface. Different routines (based on the geometry) are required to determine the location and direction of the contact patches in order to develop the correct normal and friction forces. The table below indicates some common contact surface routines that have already been developed.

2D	3D
circle-circle	sphere-shell
cam-plane	sphere-cylinder
cam-circle	sphere-torus
polyline-polyline	sphere-cone
involute-involute	sphere-sphere
ratchet-pawl	surrev-plane
	shell-plane

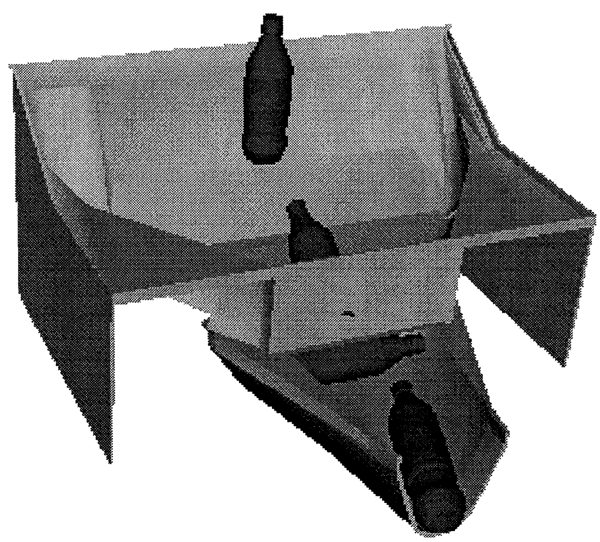
Once the information about the surface has been calculated, the third module is called. The third module is a general force calculation routine that takes the information from the dynamics code as well as the information about the contact surface and returns the components of force. The general force routine is fundamental to the methodology since it allows the analyst to focus on the surface under consideration.

HISTORICAL PERSPECTIVE

This work began as an example of how to create a general force description for a sphere to a shell. The original method included a simple searching method to determine the direction of contact, given the physical state of the dynamics system. The initial implementation was created in the commercially available ADAMS dynamic analysis software.

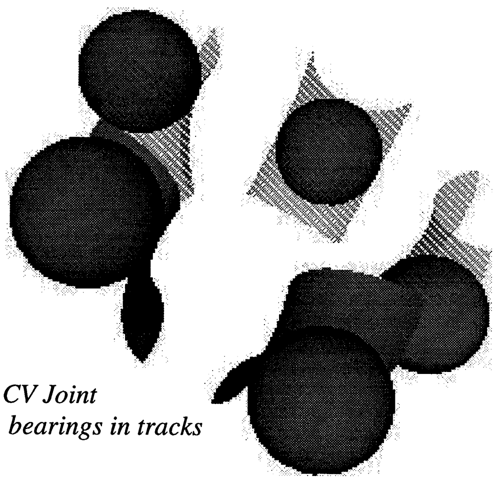
The source code for this method was distributed with the 8.x versions of the ADAMS software. This version of the method had limitations such as only accounting for sphere to shell, and the parent part to the shell geometry could not have any absolute velocities during the simulation (i.e. fixed to ground).

Required source files for customizing the ADAMS interface for incorporating the contact routines were also distributed. These "command" files facilitated the generation of the correctly formatted shell file (used as the surface definition) as well as creating the force statement with the correct parameters to pass to the contact subroutines during run time.



During the past 10 years the method has proven to be effective in accounting for many different contact requirements.

Geometry modules are added, as required, to complete projects. Also, the force generation model has been enhanced to include the ability to handle the general case of both bodies of the contact pair in any displacement and velocity configuration.



CV Joint bearings in tracks

APPLICATIONS

In the past few years, the penalty based routines have been used extensively by MDI professional services as well as ADAMS users. While the baseline ADAMS functionality and the force generation modules have remained the same, several applications have driven the development of several different geometric modules. The following is a brief list of some of the applications of these contact methods.

- Allison Trans. (parking pawl)
- BF Goodrich (disk brakes)
- Borg Warner (Silent chains)
- Borg Warner (roller chains)
- Borg Warner (CVT chains)
- Eaton (Flexible Rear Differential)
- Estech (chain)
- Fisher Price (Blow-molded tires)
- Various (CV-joint)
- Ford (timing chain)
- GM Hydromatic (Parking Pawl)
- Ingersoll Rand (misc.)
- Jaguar (valvetrain)
- JAMC (Bulldozer)
- LG (belt)
- Lucent (Shipboard Cable)
- MTC (door check)
- Firearm Manf.(Cartridge extraction)
- Electro-mech. (DY-coil)

CURRENT WORK

Hino (valvetrain)
A flat cam follower capable of contact at 8000 rpm has been developed. Work is proceeding with a circular follower to be capable of the same speeds.

TRW (seatbelt ratchets)
3-D gears capable of limited out of plane displacement, as well as extensive rachet pawl type modeling.

ADAMS 9.0 COLLISION

All of the major commercially available solid modeling and dynamics software packages contain some form of automatic collision detection. It is natural to consider the relative merits of each of the methods in determining the appropriate use for each in different situations.

The general collision functionality has several appealing characteristics that make it desirable in many situations. The collision detection is easy to use and requires little interaction from the user. It is useful for determining when collisions will occur and applying appropriate constraints to the dynamic system arising from physical contact.

However, there are some cases when the collision approach is not desirable. In cases where the analysis would be adversely affected by facetization or the loss of smooth continuous surfaces, the analytical approach must currently be used. In these cases, the time required to develop the routines that provide for specification of the analytical nature of the contact pairs is dictated.

Penalty Based Contact Characteristics

- Persistent contact
- Handles concave geometry surfaces
- Does not change constraint equations
- Fast (due to numerical efficiency)
- No facetization error (except shells)
- Handles edge contact
- ADAMS 8.x - 9.0 compatibility
- Interface independent
- Makes use of existing CAD (shell) files
- Handles static and dynamic friction.
- Stiffness based definition

Collision Detection Characteristics

- Free with most 3D dynamics software
- Easy to define (automatic surface definition)
- Easy to modify
- Works for high relative velocities
- Includes friction
- Defined with coefficient of restitution

FUTURE DEVELOPMENTS

Future development for the penalty based contact will be focused in three main areas. The next major application will be a set of geometric modules tuned for gear contact to included spur, helical, and involute gear pair contact specifications. The second leg of the continued development will be to add contact pair geometry models as they are required for specific projects. The third area of development will be to make the functionality available as a series professional toolkits.

The Analytical Contact Toolkits (to be released at the same time, but not part of the release of ADAMS 9.0)are included in the toolkit series. These toolkits will contain the required customizations to the ADAMS/View environment, as well as linkable object files to incorporate the extended functionality into ADAMS Solver. The four primary contact toolkits are as follows:

- Gear toolkit
- Contact toolkit
- Analytic contact toolkit
- Shell based contact toolkit

CONCLUSION

The penalty-based contact detection and force generation method continues to be a valuable tool in analysis of multibody mechanical systems. The method's modular approach has been shown to be suitable for continued expansion to other geometry contact pairs as required. The current contact pair functionality has been show to be of value in several real-world examples. The benefits of its analytical purity make it a suitable companion to the collision based contact offerings in commercial multibody dynamics codes.