Geometric Containment Analysis for Rotational Parts

Satyandra K. Gupta, Mukul Karnik, Edward B. Magrab

Mechanical Engineering Department
University of Maryland
College Park, MD 20742

Abstract

This paper describes algorithms and a system for performing geometric containment analysis to determine if a newly designed rotational part can be manufactured from a part in a database of existing rotational parts by performing additional material removal operations.

The system has two working modes. In the first mode, we generate a signature for each solid model residing in a database of previously manufactured rotational parts. This signature generation requires the extraction of certain geometric attributes, such as the bounding cylinder and off-axis features, from the boundary representation of the part's solid model. These attributes are stored in a signature file in a database of signature files, along with the geometric model of the part. The generation of these signature files significantly reduces the time required for subsequent comparisons. In the second mode, we compute the signature of the newly designed part and then compare its signature to the signatures of all the parts in the signature file database to determine containment.

To determine whether the newly designed rotational part Q is contained in one or more of the rotational parts P residing in the database, we use a three-step procedure based on the concept of a transformation space. The transformation space of Q with respect to P is the region in an n-dimensional space in which each point denotes a specific transformation of Q with respect to P along the n possible degrees of freedom. In the case of rotational solids, there are only two degrees of freedom: translation along the axis of rotation and rotation about this axis. Therefore, the transformation space is two-dimensional. Within this two-dimensional transformation space, there are an infinite number of permissible transformations of Q with respect to P. Hence, it becomes necessary to restrict the transformation space to a feasible transformation space. Each step of the procedure partially builds the feasible transformation space. If, at any step, the feasible transformation space is empty, then P cannot contain Q and it is pruned.

The first step of the procedure to test for containment compares the bounding cylinders of Q and P. If the radius or length of the bounding cylinder of Q is greater than that of P, then P cannot contain Q and P is pruned.

The second step in the containment determination process converts Q into a single axis solid. A single axis solid consists only of those surfaces that are rotationally symmetric about an axis such that any plane passing through this axis and cutting the solid will yield the same 2D region. Since a single axis solid has rotational symmetry, the transformation space at a given translation value is the same for all part rotations. The conversion to a single axis part allowed us to develop

an algorithm that had to determine containment status only at discrete axial locations of Q with respect to P. At each of these discrete locations, the algorithm determined containment using single axis solids. The output of the algorithm determined further limitations on the feasible transform space. Any part P that had an empty feasible transformation space after this step was pruned.

The third step in the containment determination process re-introduces, for the parts not pruned, the off-axis features, which are features that would result from the removal of material from P. Therefore, for solid Q to be contained in solid P, all the features of P must lie outside Q. If any feature of P lies inside Q and, hence, intersects Q, then the intersecting region of Q cannot be generated by performing material removal operations on P. This step involves determining those axial and rotational locations in the transformation space at which Q is contained P. These locations form the final feasible transformation space such that at every location in this space Q is contained in P. Any solid that has an empty feasible transformation space is pruned.

For all parts P that contain part Q, the system ranks P based on their volume differences with Q. The smaller the volume difference, the smaller is the amount of material removal required and, therefore, the higher its rank.

The geometric containment analysis has been implemented using C++ and the ACIS and MFC libraries. It has been tested with a database of one hundred rotational parts. The computational performance of the system has been tested by varying the complexity of Q.

The system described above can be used by designers and process planners to find an existing part that can be reused to manufacture a newly designed part. This is expected to significantly reduce proliferation of parts, to improve manufacturing responsiveness, and to reduce the cost of new products.