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An integrated design and planning environment for welding Part 2: Process planning

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Abstract

This paper describes the specification and implementation of aggregate process planning methods for complex welding operations. The methods are implemented as an aggregate process planning tool, *CAPABLE/Welding*, which can be used to evaluate the manufacturability of complex fabrications at the early stages of design. The first part of the paper discussed the aggregate product modelling methods, which are object-oriented and feature-based. The aggregate product model provides the necessary abstraction of design data to facilitate the assessment of early designs. A key planning requirement was to utilise the aggregate product model by developing process knowledge capturing and optimisation techniques so that production time and cost can be calculated for complex fabrications requiring many welding operations and set-ups. CAPABLE/Welding is a tool usable directly by designers, as it does not require specialist process knowledge. A range of generic welding process models has been developed and the planning techniques are instantiated with regard to company specific production equipment and factory layout. Alternative process and machine options are explored and the optimum production method is found using a simulated annealing algorithm. This selects process types, equipment, finds the best welding orientation, number of set-ups and finds the optimum processes and routes for minimum product cost or lead time. The resulting plans are presented graphically via a hypertext browser. This combines a graphic display of process time and cost distribution by feature with links to the relevant process knowledge. The process planning procedure of a product is used in this paper to illustrate the system functionality.

Keywords: Aggregate process planning; Welding; CAPP; DFM

1. Introduction

Extensive research in Concurrent Engineering and DFM (design for manufacture) has focused on the development of computer systems, which can support manufacturability and production cost assessment during the design process [1]. For complex applications such as mechanical design, process planning based approaches are widely used to estimate the manufacturing time and production cost [2–4]. Compared with other manufacturability assessment methods, such methods have many advantages such as the flexibility to deal with the frequently changing product data, the capability to handle the interaction among manufacturing factors and a reasonable accuracy in cost and time calculation [1].

CAPABLE is an aggregate process planning tool-kit for integrated product development in concurrent engineering environment, including functionality for machining [5] and welded fabrications [6]. *CAPABLE/Welding* is an aggregate process planning system, which can be used to evaluate the design of sheet-metal fabrications at early design stages [7]. CAPABLE/Welding has been developed by the Design and Manufacturing Group of Durham University, UK by a research project funded by the Engineering and Physical Sciences Research Council of the UK. The first part of the paper discussed the object-oriented and feature-based product model of this system. The aggregate product model provides the necessary abstraction of design information for design assessment in the early design stages. This part of the paper discusses the implementation of aggregate process planning methods and their use in evaluation of alternative design options in terms of production time and cost.

Calculation of production times and costs typically requires a process plan. For welding processes, producing such a process plan includes optimisation procedures in selecting: welding processes; welding equipment; consumables (e.g. type of electrodes); suitable materials and process parameters. All of these tasks require specialist knowledge, which is the domain of manufacturing engineers. Within a concurrent engineering team, this requires that such experts

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be on hand at all times during the design process to allow evaluation of manufacturability issues. CAPABLE/Welding is intended to support this requirement by providing an automated analysis that does not require intervention by the process expert for each design modification. This is achieved by using a process knowledge base to generate and assess process options from information in the product model and the factory layout model. This knowledge should be controlled by the company process planning experts and linked to an up-to-date factory database. The mode of operation is for designers working on a CAD system to intermittently submit their current design model to CAPABLE/Welding via an extension to the CAD system. The analysis would run as a background task and return both a quantitative analysis of cost implications of each design feature and details of the selected process that would inform further design refinements. This prototype system developed uses an X-Windows interface for input and a hypertext browser for results.

2. Functions of aggregate process planning for welding

The main aggregate process planning set-ups are:

1. Raw aggregate plan creation.
2. Process selection.
3. Welding process orientation and set-up optimisation.
4. Equipment and consumable selection.
5. Process sequencing.
6. Manufacturing lead-time and cost calculation.

Optimisation methods are used in many of these functions, such as process selection and equipment selection. These functions are normally performed in a sequential way, including the consideration and satisfaction of relevant process constraints, such as material thickness.

2.1. Raw aggregate plan creation

The raw aggregate plan consists of the routing objects without defined process or resource options. Each feature and part of a product model has a corresponding object in the process plan. Fig. 1 shows an example process route. The top level modelling object is the "fabrication job", which consists of a group of child fabrication jobs for all bends and cuts, and a single set-up (shown as *fix*0, etc. in Fig. 1) for all welding-related operations. Extra set-ups may be added later by the system if these welding operations cannot be completed in one set-up because of process constraints such as process orientation. Rules in the system may be used to determine process sequence based on this structure. For example, *fab_job*1 in Fig. 1 must be completed before performing *fab_job*0. Those jobs directly attached to *fab_job*0 (e.g. *job*0 and *job*1) must be finished before the welding set-up *fix0*. This is because the fabrication cannot be made before its sub-fabrications are ready, and the bends and cuts

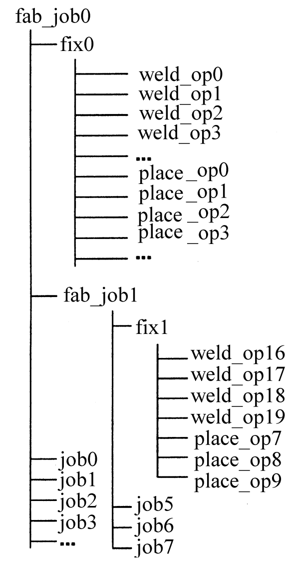

Fig. 1. An example process route.

must be created before welding as they belong to the child components of the fabrication.

2.2. Process selection

Once the initial process route has been created, a set of process options, such as MIG and TIG, can be generated for each job or weld operation. These process options are automatically selected by the system using its process knowledge base. Process constraints are applied according to part geometry. During the process selection procedure, appropriate process types are chosen for the jobs from the process options generated at the previous step. Process selection aims to optimise the production cost and lead-time, using known factory data and generic process cost models. Simulated annealing (SA) is used to identify optimal solutions for the shortest lead-time and lowest cost.

SA is a general purpose optimisation technique, which simulates the physical process of metal annealing. Its initial form, Monte Carlo integration algorithm, was introduced by Metropolis [8] and the algorithm was later generalised by Kirkpatrick [9] who introduced a temperature schedule in the algorithm for efficient searching. It has been proved that SA algorithms can: (1) process objective functions which possess quite arbitrary degrees of non-linearities, discontinuities and stochasticity; (2) process quite arbitrary boundary conditions and constraints imposed on these objective functions; (3) be implemented easily with a degree of coding quite minimal relative to other non-linear optimisation algorithms; and (4) statistically guarantee finding an optimal solution [10]. Therefore, the SA algorithm is selected as the optimisation method in aggregate process planning. The SA algorithm has been implemented as a C++ program. Each valid process type is presented in the program with an integer code. The program searches for the optimum solution by changing the process code for each job and calculates