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Technical paper

A hole-machining process planning system for marine engines

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ABSTRACT

This study proposes a hole-machining process planning system for marine engines, which converts industrial field requirements to the rules of the system. Unlike a fully automated system, the proposed system satisfies the requirements effectively by allowing the user to choose and to edit the rules. A computer-aided process planning (CAPP) system is comprised of Hole Manager, Cutting Sequence Definition, and Operation Manager which are derived from the conventional knowledge based system. For the purpose of efficiently coordinating the system operations, a procedure is proposed as: (a) defining priorities for each operation, using properties for the nested cutting, the number of tool changes, the directions of the tool, the tool diameter, and the hole height, (b) calculating the score for each operation with the related priority level, and (c) sorting of operations by the score in an ascending order. This idea is quite simple but yields a significant efficiency along with a high flexibility. By changing the priority of elements, various operation sequences can be obtained. The proposed method also considers multi-axis machining and the use of special attachments. This paper describes the construction of a practical hole-making CAPP system that satisfies the specific requirements of marine engine machining. The applied examples are machined by using the proposed system, including an engine block and a cylinder header.

1. Introduction

Computer-aided process planning (CAPP) is one of the most important steps in a manufacturing system. Various conditions and resources affect the total efficiency of the manufacturing system. The tool traveling and tool changing time comprises of a large portion among the total time in a manufacturing process while the optimization of these processes can contribute greatly to the total efficiency of a manufacturing system.

Recently, many CAPP relevant studies have been carried out to improve productivity and the research scope has been expanded to the system level. For an illustration, the construction of a knowledge-based system and knowledge management in relationship with product lifecycle management (PLM) and enterprise resources planning (ERP) systems are embedded in CAPP. There has been significant increase in the number of researches and developments of the CAPP system being published recently. However, a viable off-the-shelf solution has not been commercialized due to the complexity of the CAPP system, and abundances of the interdependent requirements and conditions [1].

1.1. Knowledge-based system overview

Due to the needs of satisfying the requirements of industry, the knowledge-based system has received a great deal of attention from researchers. Park [2] proposed a knowledge base as a framework of process planning while customizable rules and a chosen methodology can be used for the control. The methodology has four knowledge elements: facts, constraints, modes of thinking, and rules, which are derived from a traditional three-phase modeling framework. Denkena et al. [1] suggested standard stages of a constructing process planner environment and a holistic PLM/CAPP solution construction methodology. In this approach, the ontology structure was used to make explicit knowledge contained within the system application.

Once a knowledge base is constructed, the appropriate decision-making techniques are applied to explore the large solution space effectively under various constraints. These techniques adopted heuristic approaches, fuzzy logic, expert systems [3], reasoning-based approaches [4] and neural networks. Many studies have addressed the implementations of automated operation planning

Abbreviations: CAD, computer-aided design; CAM, computer-aided manufacturing; CAPP, computer-aided process planning; ERP, enterprise resources planning; MCS, machine coordination system; MEMS, microelectro-mechanical systems; PLM, product lifecycle management; PSO, particle swarm optimization; TSP, traveling salesman problem.

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and tool selection algorithms. Generally, a Petri-net model has been regarded efficient in minimizing the number of tools and setup changes [5]. Branch and fathoming algorithms provided optimal and near optimal solutions for problems associated with the operation sequencing [6]. Simulated annealing algorithms optimized the selection and sequencing operations [7]. Relevant to the operation sequence and tool selection, heuristic combined knowledge bases were used [8–11]. Regarding the tool path planning, the heuristic approaches which are capable of providing near optimal solutions with relatively little computational effort have been widely proposed. These are Tabu search algorithms which minimize the total processing cost of tool traveling, tool changing, and the tool cutting time for hole-making operations [12]. A new approach based on particle swarm optimization (PSO) also has been introduced for drilling path optimizations [13]. An ant algorithm minimized the summation of the tool traveling and tool changing time [11].

On the basis of these decision techniques, there have been several attempts to construct practical CAPP systems. These include surface micro-machined MEMS devices [14], an activity model which defines sheet metal process planning [15], a feasible approach to the integration of CAD and CAPP [16], and an assembly/disassembly sequencing process [17,18]. Denkena et al. introduced a holistic process-planning model based on an integrated approach combining business and technological considerations [19]. Halevi and Wang introduced a road map method for flexibility and dynamics in the manufacturing process and thus simplified the decision-making process in production planning [20]. To meet the requirements of large variety of products in small batch sizes, Wang et al. proposed distributed process planning using function blocks [21,22]. In this research, function blocks can generate detailed and adaptive operation plans at runtime to best utilize the capability of the available machines, and the tasks of process planning are divided into two groups: shop-level supervisory planning and controller-level operation planning. Further, Wang et al. showed a hybrid approach using both knowledge-based and geometric reasoning rules in sequencing of interacting prismatic machining features [23]. Recently, he reviewed function block-based process planning and execution control systems [24]. The past and recent CAPP researches have been summarized in a number of categories by Xu et al. [25], i.e. feature-based technologies, knowledge-based systems, artificial neural networks, genetic algorithms, fuzzy set theory and fuzzy logic, Petri nets, agent-based technology, Internet-based technology, STEP-compliant CAPP and other emerging technologies.

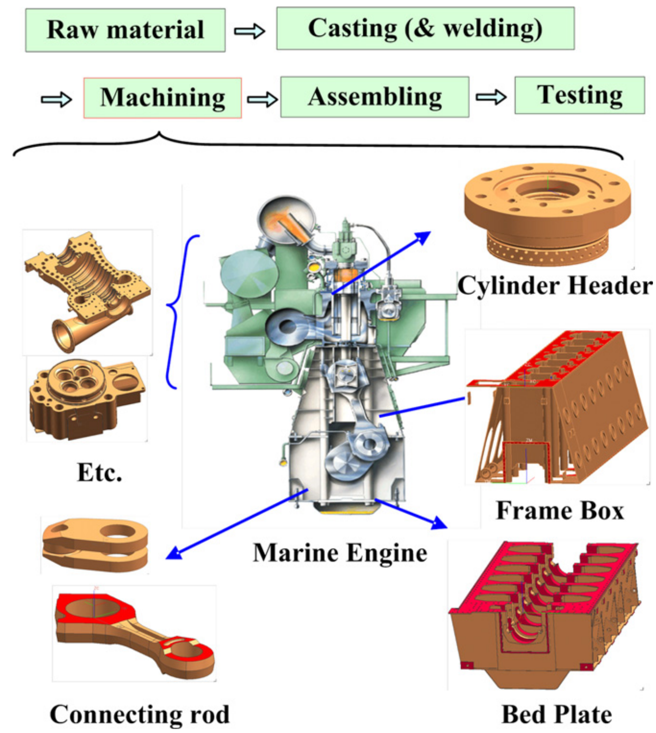

Fig. 1. The manufacturing process of a marine engine.

The ultimate objective of a CAPP system is to reduce the degree of human judgment in the process planning. The CAPP system of the above techniques, however, has a limitation in a direct application to the industrial field. Furthermore, the construction of a new CAPP system from the ground up requires a considerable amount of time. In this paper, thus, a hole-making system which has been developed with the knowledge from a domain expert is embedded into a commercial CAD system.

1.2. Proposed system

Fig. 1 shows the manufacturing process of a marine engine where the final product consists of several parts. The assembled faces of the parts are machined by face-milling and hole-making prior to the assembly. The holes serve to hold the parts together and they are designed to endure high temperatures and high pressures.

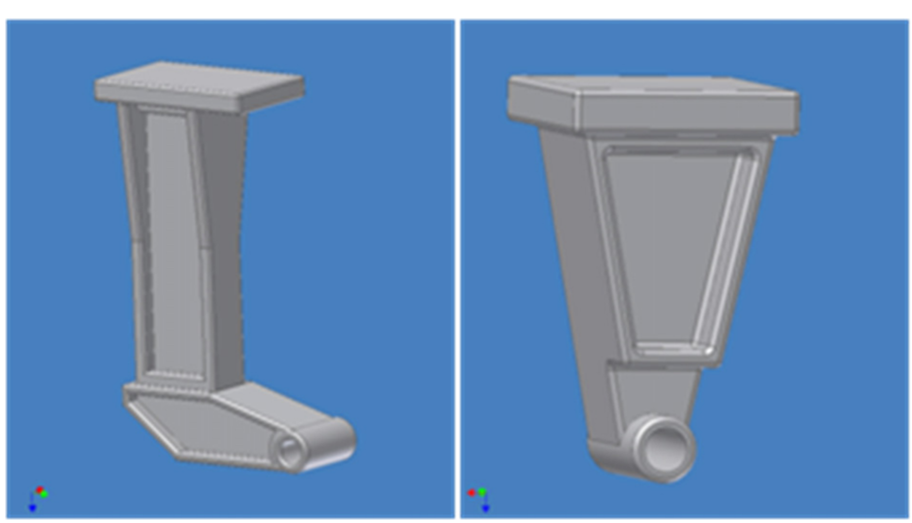

Fig. 2. Some examples of attachments to machine holes.