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Hydrogen fuel cell pick and place assembly systems: Heuristic evaluation of reconfigurability and suitability

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Abstract

Proton Exchange Membrane Fuel Cells (PEMFCs) offer numerous advantages over combustion technology but they remain economically uncompetitive except for in niche applications. A portion of this cost is attributed to a lack of assembly expertise and the associated risks. To solve this problem, this research investigates the assembly systems that do exist for this product and systematically decomposes them into their constituent components to evaluate reconfigurability and suitability to product. A novel method and set of criteria are used for evaluation taking inspiration from heuristic approaches for evaluating manufacturing system complexity. It is proposed that this can be used as a support tool at the design stage to meet the needs of the product while having the capability to accept potential design changes and variants for products beyond the case study presented in this work. It is hoped this work develops a new means to support in the design of reconfigurable systems and form the foundation for fuel cell assembly best practice, allowing this technology to reduce in cost and find its way into a commercial space.

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Keywords: Reconfigurability; hydrogen fuel cells; pick and place; assembly

1. Introduction

Climate change and human health concerns associated with the combustion of fossil fuels are putting increased pressure on industry to develop and implement more efficient, less polluting power generation and storage technologies. One such technology is the hydrogen fuel cell, an electrochemical device that generates electricity and produces water as the only emission (Fig. 1a). Despite its benefits the fuel cell costs remain at least an order of magnitude greater [1, 2] than targets that would allow it to compete with internal combustion engines *i.e.* 30\$/kW-50\$/kW [3, 4]. These higher costs are attributed to: inadequate product durability, expensive component materials, and immature manufacturing and final assembly methods. Methods and considerations for fuel cell product assembly are limited in the literature. The author believes that this lack of exploration into manufacturing assembly strategies and systems are one of the key barriers to more widespread commercialization of this technology. It is important for a fuel cell manufacturer to have the confidence that an assembly system is suitable for a product, but is also able to efficiently handle future changes and variants which are inevitable due to the vast range of potential applications (Fig. 1b). The manufacturing paradigm that this aligns with is that of reconfigurability which accommodates the high volume throughput of dedicated lines, the flexibility of flexible systems, but also react to change quickly and efficiently [5, 6]. The purpose of this research is to therefore investigate what reconfigurability means within the context of assembly systems, how that can be measured, and the effect this has on suitability to a product family. This is carried out by evaluating real fuel cell assembly systems, comparing them to a conceptual system which is designed with reconfigurable principles in mind and assessing suitability using a knowledge-based approach that maps product characteristics to assembly system components.

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2. Review of literature

2.1. Defining reconfigurability

The concept of reconfigurable manufacturing systems (RMS) has been defined in a number of different ways. Koren describes it as a system that, at the outset, is designed for a change in structure both from a hardware and software perspective [5]. Makino and Trai focus on the geometric setup changeability and describe reconfiguration as a characteristic of flexible assembly systems, categorizing them into statically and dynamically reconfigurable [7]. Lee defines reconfigurability as the ability to economically reconfigure a system, however there was also a focus to design a product such that reconfiguration was minimized [8]. Furthermore, concepts similar to that of reconfigurability have been proposed using alternative terminology such as 'evolvable', 'holonic', 'modular manufacturing', 'component-based manufacturing' and more [9]. However, the common objectives of all of the research in this area is to accommodate change and quickly react to uncertainty both within the system and externally [10].

2.2. Reconfigurable assembly systems (RAS)

The enabling technologies for RASs are [11]: 1) modular manufacturing system equipment and distributed control [12], and 2) methods that facilitate rapid system re/design and re/deployment [6, 11]. The objective of an assembly system is to realise every part liaison to a given specification to form either a sub-assembly or final assembly. While a dedicated system meets this objective for a given product, the RAS is designed to accommodate a product family and product design changes (*customization*), introduction of new process technologies (*convertibility*) and volume fluctuations (*scalability*) using functionality embedded into 'plug and play' components (*modularity, integrability*) in a maintainable way (*diagnosability*) to facilitate the paradigm shift away from mass production and towards mass customization [5, 12]. Comprehensive reviews of flexible and reconfigurable assembly systems are presented in [7, 12]. The differentiation between these systems is that the former has *general* flexibility, whereby the system can produce almost any product that can fit on the machine, which is not true for RAS [13]. The literature identifies the following as core components of an RAS [7, 10, 12, 14, 15]:

- Mechanisms for transferring parts within and across stations that have a flexible level of reachability and can quickly adapt to changes in positional requirements
- Jigs, fixtures and clamps for holding parts during processes and transport that are designed with a part/product family in mind with adaptable features to support alignment and holding
- Buffering and storage systems to hold parts prior to being introduced into the system that have positional changeability
- Feeding mechanisms to transfer parts from storage to be processed that have positional changeability
- Gripping or manipulation tools to handle parts that have changeable functionality due to inherent modularity and that efficiently integrate with the moving mechanism

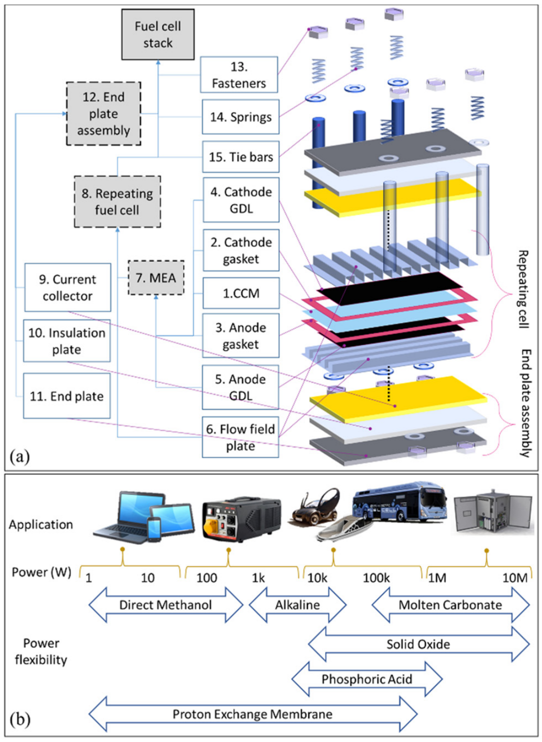

Figure 1 (a) Fuel cell and bill of assembly (b) Application of various fuel cell types

2.3. Design evaluation of RAS

Evaluation of an RAS at the design stage is essential to determine the nature, degree and appropriateness of the reconfigurability. A design structure matrix was used to assess the reconfigurability of a distributed manufacturing system using the nature and number of interactions of manufacturing system components to allow the designer to identify where the interactions are greatest, from which a lack of modularity and thus reconfigurability can be inferred [15]. A convertibility measure that considered configuration, machine and material handling convertibility produced numerical values generated in part from quantifiable features and in part from a series of questions to identify the nature of the system allowed comparison of system designs at the early system design phase [16]. Several fuzzy approaches are present in the literature that measure system flexibility identifying criteria and rules that lend themselves to measuring reconfigurability [17-19]. Koste et al. presented an approach to measuring manufacturing flexibility by identifying key dimensions of flexibility and use Churchill's paradigm [20] to demonstrate the weighting that can be given to these metrics (some of which are shared by RAS) based on the experience and expertise of industry [21]. Finally, the application of complexity theory to heuristically compare system designs can be adapted to measure reconfigurability, using a framework that considers the