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Development Of Scalable Production Concepts For The Cost-Efficient Assembly Of PEM Fuel Cell Systems For Mobile Applications

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Abstract

Polymer-Electrolyte-Membrane (PEM) fuel cell systems will contribute to enable climate-neutral mobility through the chemical reaction of hydrogen and oxygen. PEM fuel cells address applications which are hardly decarbonized by HV batteries. But apart from its advantages, such as short refuelling times and higher energy densities related to batteries or locally emission-free operation compared to conventional drivetrains, the fuel cell technology still faces challenges that inhibit its wide market penetration. Especially the low production volumes result in costly manufacturing processes. The assembly of the fuel cell stack and balance-of-plant components to a system is predominantly of manufactory character. There is a consensus in the literature that scaling up the production is associated with cost reduction effects. But in order to increase the demand that justifies a growth in unit numbers, the costs per system have to be reduced. With regard to this so-called "hen-and-egg problem", a reduction of production costs for small output numbers is necessary, while already considering the future necessity to scale the production.

This paper discusses the development of scalable production concepts for PEM fuel cell system assemblies. In addition to a modular production concept, the associated production scenarios are also considered. For a generic fuel cell system, a possible assembly sequence and assembly tasks are derived from the bill of materials. The assembly durations for the individual steps are then determined according to the Methods-Time-Measurement (MTM) methodology. This methodological approach is intended to provide an estimate for each process step in the assembly and can be transferred to other fuel cell systems. The paper shows how a bill of materials can be used to estimate the cycle time for a system, but also the cycle time for defined stations. In addition, by considering different scaling mechanisms, further improvements in the assembly process are shown, based on the results from the MTM analysis.

Keywords

Fuel Cell System Assembly; PEM Fuel Cell System; Scalable Production Concept; Methods-Time-Measurement; Assembly; Production

1. Introduction

The fuel cell system assembly and End-of-Line-Testing (EoL) is the final step in the value chain of the fuel cell system production [1]. Since it is by now mainly conducted in small scale and manual labor, it is still a cost intensive part within the manufacturing process, taking a share of about 7 % in the cost breakdown of the fuel cell system manufacturing costs [2]. A reduction of the fuel cell system costs is crucial in order to

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allow market penetration and therefore a decrease of assembly costs would contribute to this goal. This cost reduction can be achieved with scalable concepts allowing the production to follow the fuel cell system demand at low-cost investment decisions and at the same time result in a higher level of flexibility for the production system to adapt to system design changes. In this work, an approach will be discussed, which is based on the number of parts of a generic fuel cell system. Different to the approach from JAMES ET AL. [3], it will be combined with the MTM (Methods-Time-Measurement) approach. Three mechanism, that allow scaling of the production output will be explained and based on two of those mechanisms, a scalable concept for the assembly of fuel cell systems introduced.

2. Objectives & state of the art

2.1 Fuel cell system set-up

The main component of the PEM fuel cell system is its stack, where the reaction of oxygen and hydrogen takes place. Apart from the stack, the fuel cell system needs subsystems to supply the stack with the necessary reactants. Those subsystems can be summarized under the term Balance-of-Plant (BoP). The BoP can be differentiated into the anode system, cathode system, cooling system and power and control unit. **Figure 1** yields an overview of a possible system set-up. Whereas the cathode system includes components like air filter, compressor, turbine and humidifier to lead the filtered and compressed air to the stack, the anode system contains components like the hydrogen storage, solenoid valves, pressure reducer, purge and drain valves and ejector or recirculation blower units for circulation of hydrogen through the system. The cooling system mainly includes thermal management components such as the radiator, heat and ion exchanger and cooling pump. The power and control unit includes a power distribution unit as well as the control unit with all the interfaces for cables transmitting electrical power or data. These cables are connected to all sensors allocated within the other subsystems like pressure, temperature or hydrogen sensors. [4]

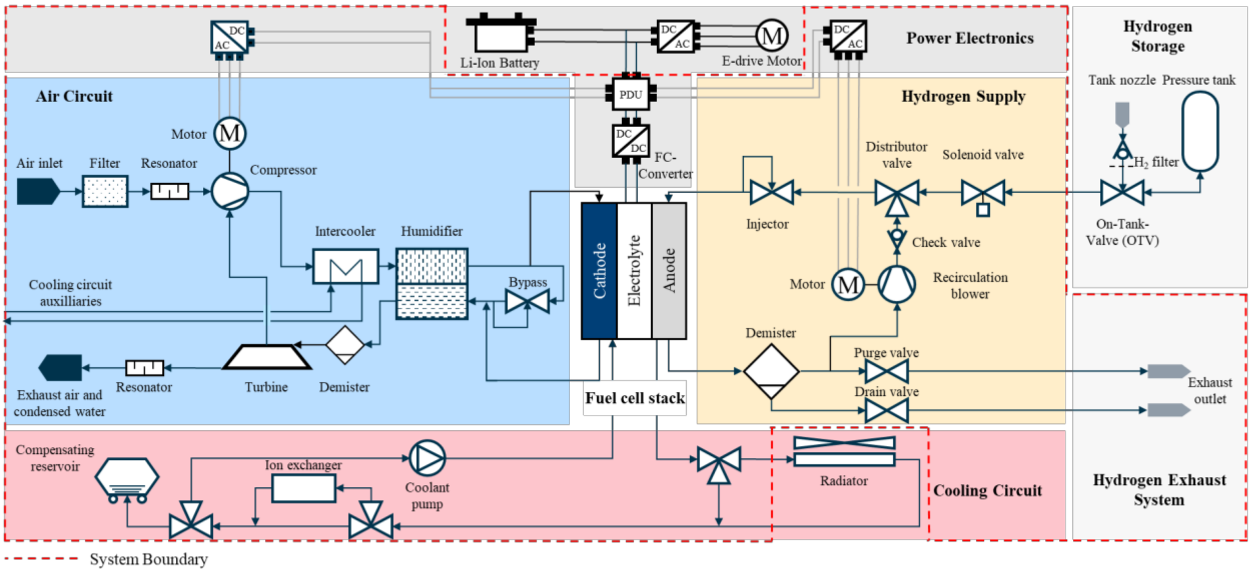

Figure 1: Generic and simplified fuel cell system for the definition of assembly contents adapted from PEM RWTH Aachen [4]

2.2 Fuel cell system assembly

The assembly of the fuel cell stack with BoP components is a currently not scientifically discussed part of the fuel cell system value chain. One early approach for estimating the assembly and cycle time of the assembly of fuel cell systems is undertaken by JAMES ET AL. [3], [5] in the context of an overall estimation of the production cost of fuel cell systems. This approach was conducted within an analysis of an automotive fuel cell system with a net power output of 80 kW in the year 2018. In this former approach a heuristic estimation based on the approximate number of parts was conducted. The various parts of the system were differentiated into major components such as the stack, pumps, motors and compressors and minor components such as measuring instruments and devices. For additional activities such as welding, piping, wiring etc., static assembly times were determined, based on the sole differentiation between major and minor components. These durations for piping, welding and a functionality test were added and led to a total system assembly time of 177.1 minutes at a single work station [3], [5]. This approach does not take the real number of components into account and therefore does not allow a detailed analysis of the assembly contents and associated cycle times. A static value for the time needed to assemble was assigned to each kind of component of the previously described groups, so that the components in one group all have the same assembly duration. In a second approach for the scale-up of production output, a system with ten workstations was introduced, that should reduce the cycle time to 14.2 minutes per station. In a further estimation for different scaled up production systems, JAMES ET AL. [3] estimated, that for an annual production volume of 1,000 systems, the cycle time drops to 9.9 minutes and the line utilization amounts to 2.2 %. This configuration is based on a single assembly line with 18 workers and ten workstations. From a production volume starting with 10,000 systems up to 500,000 systems per year a different configuration is needed, and the cycle time decreases to 7.9 minutes per system. [3]

In order to put these results into perspective, the values were compared to data known from industrially used fuel cell assembly systems. Within the production of the Mercedes-Benz GLC F-Cell fuel cell system in the year 2018 the assembly time is yielded 300 minutes [6] and a subsequent time for End-of-Line-Testing is added with 90 minutes [7]. The system contains around 250 parts [6]. The assembly takes place in an assembly system equipped with an electric monorail conveyor system, where the fuel cell system is hung in and can be rotated to get better angles for the assembly processes. Leakage tests for subsystems are included within the assembly procedure and conducted at the assembly line through a sniffer sample. [8]

2.3 Fundamentals of production technology

In the following, specific terms within production technology will be further explained. The terms of flexibility investigated in this work focus on the flexibility of variants and flexibility of production volume.

Flexibility in the context of production technology describes the time as well as the effort necessary to change over a production according to altered basic conditions. In order to measure the required effort, changeover times are introduced [9]. Flexibility of variants on the other hand can be understood as the ease with which new parts can be added or substituted within the production [10]. Therefore, the flexibility of variants of products can be defined as well as the ability of a production system to adapt changes in the part matrix currently produced rapidly and inexpensively. This means, that the change in parts still goes along with a change in the production system set up and therefore distinguishes the flexibility of variants from the flexibility of process [10].

Within the ongoing production, the assembly system can be adapted for new products as identical assembly activities can take place on different assembly cells. Individual assembly cells on the other hand need to be deactivated or reconfigured. For the integration of a new product within a mixed-model assembly, the assembly line requires a complete redesign and synchronization and also isolated additional assembly activities can cause a modified balancing of the assembly line. [11]

Scalability can be described as the ability to extend or restrain a system by either adding or reducing its resources. This can be a matter of technical, organisational or spatial resources. [12] Scaling mechanisms can be differentiated in three groups, which consist in intrastationary and interstationary scaling mechanisms as well as organisational scaling mechanisms. Whilst organisational scaling mechanism can be applied through changes in the number of workers or different shift models, for the two other types of scaling mechanisms a different architecture of the production system is needed. Hence the intrastationary scaling mechanisms foresee an adjustable level of automation, the rearrangement of assembly tasks and the reconfiguration of a production system section. A production system section can be understood as a part of the production system. The interstationary scaling methods on the other hand are provided by the duplication of system sections or the duplication of the whole assembly system. [13]

2.4 Methodological approaches existing

The methodological approach relevant for this study, the Methods-Time-Measurement (MTM) will be further explained in the following.

The MTM is a commonly used method in manual assembly processes to investigate and determine times within manual assembly. Through MTM it is possible to track the specific time that is needed for different types of motions in assembly and production. As MTM aims to optimize existing processes in assembly, it can also be used in the phase of planning assembly processes. Therefore, all the motions within the manual assembly process are divided into smaller motion sequences, that are categorized and structured. Afterwards these TMU (Time Measurement Units) can be allocated to the motion sequences. One TMU equals 10^{-5} hours, which is the equivalent of 0.036 seconds [14]. [15]

For this purpose, the correct MTM data map must be used, as there exists a variety of maps published by REFA AG. Therefore, REFA proposes a method including six steps to determine the times in assembly processes. In a first step the correct MTM scenario is chosen in accordance with the process type within the production system, the methodological level and the targeted production output [16]. Subsequently, the conditions and circumstances at the workstation are further examined. Therefore, especially the supply with working material and the working conditions at the workstation are relevant. In the third step, assembly contents and assembly sequences are either analyzed for existing assembly processes or planned for new assembly processes. An assembly content consists in the task of joining and assembling components. Afterwards, these assembly sequences are differentiated into the basic motion sequences of the respective MTM process. During the fifth step, these basic motion sequences are coded, taking the relevant influencing variables and the correct MTM data map into consideration. Finally, the times for manual assembly from the MTM data map are assigned to the coded basic movements and the activity times of the workflow are determined by adding the individual TMU values. The described procedure for determining times in manual assembly with MTM is shown below in Figure 2. [17]

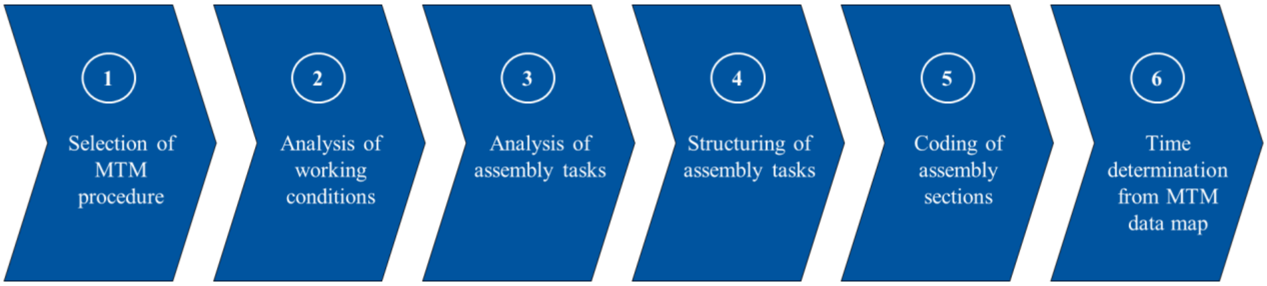

Figure 2: Methodology for determining the duration of assembly tasks in a manual production through MTM adapted from REFA [17]

3. Methodological concept

3.1 System definition

A generic and simplified PEM fuel cell system consists of a basic configuration of a PEM fuel cell stack and its periphery components. The system boundaries of this generic fuel cell system exclude the radiator unit from the cooling circuit and the hydrogen storage system. As well not included is the cooling circuit supplying the auxiliary units, which consists of the intercooler, the compressor and power distribution unit. Drawing these boundaries, the generic and simplified fuel cell system contains the fuel cell stack, the high temperature cooling circuit (without the radiator), the anode system for supplying the stack with hydrogen and the cathode system for providing oxygen from ambient air to the stack. Such a generic fuel cell system can still differ in many ways in its interconnections and therefore in its assembly process. **Figure 1** gives the exact picture of the generic fuel cell system, which was used for the development of scalable production concepts within this work.

3.2 Definition of assembly contents and deriving the assembly time

In the first two steps of the methodological approach of deriving determined assembly times with MTM, the MTM data card UAS (Universales Analysier-System, English: Universal Analysis-System) was chosen, and the working conditions for this mainly manual assembly were defined [16]. The choice for the MTM data card UAS was reasoned by the aim to analyse and plan assembly contents for series production, whereas the MTM standard includes data cards for mass manufacturing processes as well. Within the third and fourth step of the MTM methodology, the assembly contents were determined and structured into repetitive assembly sections. The assembly contents therefore were derived from a Bill-of-Materials (BoM) (Table 1) and the fuel cell system layout, yielded above. The BoM contains all components of the defined fuel cell system including connection elements such as pipes and hoses. As well included are brackets and screws to mount to components around the stack and frame. For wiring the power electronics and the control unit with motors and sensors, the BoM contains also cables for transmitting power and data. Due to the analysis of the fuel cell system an assembly sequence for each module of the complete fuel cell system was elaborated. It was assumed that the subsystems will be assembled continuously around the stack. At first the overall assembly task is determined. Afterwards the assembly of each module can be further divided into sections. An exemplary section is shown in Figure 3 and visualizes the assembly content beginning at the air inlet of the cathode system and ending at the humidifier. In a subsequent step, those sections are examined further to determine on a next dimension the necessary motions for joining two components such as the air inlet pipe and the air filter.

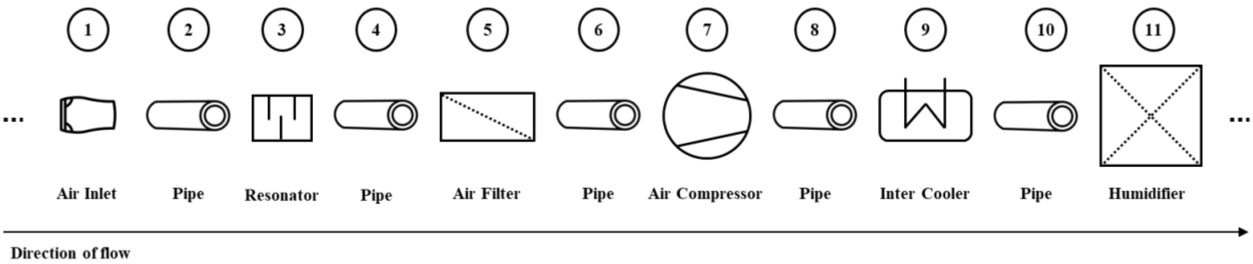

Figure 3: Example of an assembly section in the cathode system

3.3 Development of a scalable production concept

For the development of scalable production concepts in the fuel cell system assembly, a scenario where the production volume was scaled up from 1,000 systems to 10,000 systems was examined. These scales are in line with current market information that announce similar production volumes [18], [19]. Scalable production concepts were derived by comparing the production of fuel cell systems to that of battery systems, electrolysers, electric motors and combustion engines. As an evolution from the current status of manual assembly, a scalable production with features from a series production was targeted. The screening concluded that despite of their similarity in system structure and technology, electrolysers have larger dimensions and therefore favour manual assembly conditions with high manufacturing character and low production volume. Hence, those systems were excluded from the further procedure. From the other technologies, which differ a lot in their technological structure from the fuel cell system but have similar scale-up scenarios and targeted production volumes, assembly concepts were derived. Those concepts comprise for example an increasing degree of automation [20], [21], [22] hybrid assembly structures [21], [23] modular assembly structures [23], [24], human-robot-collaborations [21], [25], approaches including augmented reality for variant flexibility [21], approaches of machine learning in automation [25], digital twins for testing [25], a separation of assembly tasks into pre- and end assembly [26], [27], [28] and the implementation of automated guided vehicles (AGV) [24], [25] or conveyor systems [24] for high and stable production volumes. For this study it was decided to apply the separation of assembly tasks into pre- and end assembly and to develop modular assembly structures. This can be justified by the fact that the fuel cell system assembly contains numerous assembly sequences like wiring, or joining hoses and pipes, that are currently hard to automate as robots are limited in their assembly adaptability in complex assembly environments [21], [29] .

The existing and accessible assembly systems of fuel cell systems were investigated. The fuel cell system production of Mercedes Benz AG for the GLC F-Cell and the production system of HYVIA, a joint venture between PlugPower and Renault for a 30 kW range extender system, were further analysed [30]. The assembly system of Mercedes Benz was chosen as reference system as it was set up for series production, which is also targeted within this work**.** In this production system, the fuel cell system was mounted onto an electric monorail system that carried the fuel cell system through the assembly line. This line contained several workstations, where the electric monorail system with its mounting aid could be stopped at the positions, where racks with the supplying material for assembly or testing infrastructure were located. [8], [28]

Based on this assembly system, a reference system was developed and unknown parts were adapted from literature or other productions [5], [27], [28]. The assembly line of this reference configuration was assumed with six workstations using the electric monorail system and structured comparably to the production of the GLC F-Cell system. The configuration of this reference assembly line, is shown on the left in **Figure 4**. It was assumed, that the system would be assembled continuously without integration of pre-assembled modules. On the other hand, the scalable concept with a modular configuration in its production system design is visualized on the right in **Figure 4.** It as well contains six workstations for the manual end assembly, but in addition there are three workstations for the pre-assembly of sections of subsystems. The stations are connected via an AGV and can be scaled-up separately if required.

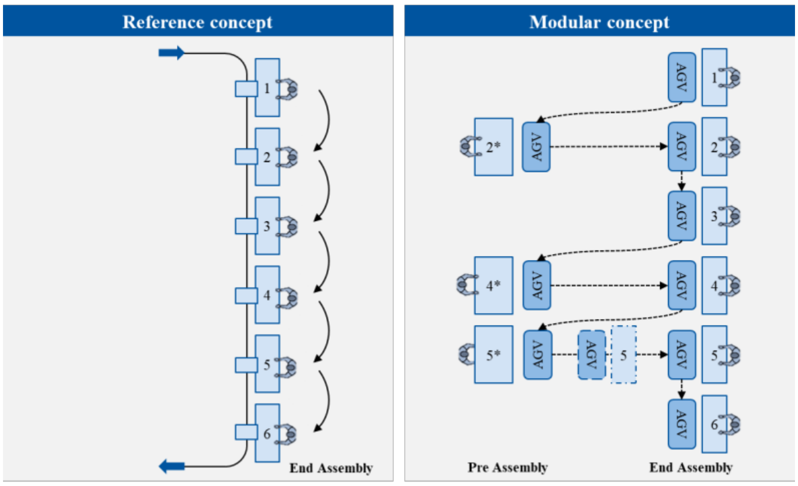

Figure 4: Assembly line configurations examined in this work

The scalable concept developed for the fuel cell system assembly shall be introduced in the following as the modular concept. The concept includes the separation of assembly tasks into a pre- and end assembly and a modular assembly line structure. Regarding the scaling mechanism explained above, the separation of assembly tasks can be allocated to intrastationary scaling, whereas the modular assembly line structure has to be allocated to interstationary scaling. This modular assembly line structure consists of the workstations for the pre- and end assembly. The AGVs connect the workstations among each other in a flexible way and hereby allow elementary changes within the structure of the assembly system. This allows flexibility in variants as well as in volume since single workstations can be duplicated and therefore bottlenecks in an unbalanced system can be reduced swiftly. The assembly line layout therefore is structured in three pre-assembly stations and six end assembly stations. The assembly within the reference and as well the modular concept was planned with the same distribution of assembly contents on the planned stations. At station 1, the fuel cell stack will be lifted by crane into the fuel cell housing and afterwards locked by screwing the media distribution plate with most of the media interfaces. At station 2, the complete anode circuit will be assembled around the housing by screwing and fixating the hydrogen lines with brackets. It was assumed that on a third station, larger components like the compressor, power distribution unit and fuel cell control unit have to be mounted around the housing due to the geometrical restrictions and further accessibility for following assembly operations. On station 4, the entire cathode system is mounted and subsequently on station 5 the whole cooling system finalized. Subsequently to mounting the fluid containing systems around the housing of the stack, an interim leakage testing will be conducted on station 5. This is due to the possibility of rework in case of a failed test. Finally, on station 6 the electronic assembly and wiring is concluded and the system can be removed from the monorail mounting aid.

3.4 Transition from a qualitative concept to a quantitative model

In this chapter, the concept introduced in chapter 3.3 will be evaluated. Therefore, the theoretical and qualitative concept will be transferred into a quantitative model through applying MTM.

For the motion sequences that are assumed to repeat in specific patterns in the overall assembly for several times, codes are defined regarding the MTM methodology and the MTM data map [16]. These codes can be translated within a next step into TMU values, which afterwards can be converted into seconds or minutes. **Table 2** yields an impression of the determination of the TMU values for the assembly of a generic pipe section.

A recombination and reallocation of the assembly contents is conducted aiming to determine suitable assembly sections, that can be outsourced in the pre-assembly. Those pre-assembly contents require to be mountable from chronological later positions within the assembly process and therefore also must meet topological restrictions within the assembly sequence.

In order to determine possible output scenarios for a fuel cell system assembly based on the developed assembly sequence, the durations generated by the MTM-method were transferred into an output model. Therefore, an organizational model of one shift per day with 8 working hours, and 220 working days per year were assumed. Through the cycle time, which is specific for the configuration of the production system, the total possible amount of assembled fuel cell systems per year could be determined. The different production systems will be compared in their demand for assembly personnel and the demand of simultaneous assembly lines.

4. Results and discussion

The application of the MTM methodology under the premise of the derived assembly contents from the BoM resulted in an overall assembly time of around 100.7 minutes for the generic and simplified fuel cell system. By duplication of the workstation with the largest station time, the cycle time of the whole production system decreases to the level of the station with the second largest station time. The station time of this workstation then becomes the new cycle time. The assumed cycle time of the reference concept was determined to 43.97 minutes, including an additional 25 % of estimated set-up time [3]. The cycle time of the modular concept resulted to 30.85 minutes, and could be further decreased to 16.79 minutes by duplication of workstation 5 or to 15.01 minutes by duplication of both, workstation 5 and 6. Transferring these cycle times into possible production volumes as described above, leads to capacity demands in simultaneous assembly lines and personnel for the compared production concepts. The diagrams in **Figure 5** show the development of the demands within the scaling from 1,000 systems to 10,000 systems per year. Whereas the reference concept initially starts with a lower demand for personnel, the modular and therefore scalable concept shows a higher, but for a larger output corridor more stable, demand for personnel. This can be explained by the effect from separation of assembly contents. It is assumed that the pre-assembly and the end assembly can be conducted at the same time and therefore the end assembly at different stations can be reduced. This results in a lower cycle time for the modular concept. The demand for personnel is connected to the number of necessary simultaneous production lines. Within the production volume corridor of 1,000 up to 6,000 fuel cell systems per year for the modular concept, the demand in simultaneous production lines is stable. In the reference concept, which was assumed less flexible in its configuration, a change in production volume of the system results also in a necessary scale-up of this system. Hence, the demand for assembly lines and assembly personnel increases almost linearly. The modular concept therefore has due to its structure the ability to scale-up the production output with less capacity in assembly lines and personnel over the observed production volume corridor. The higher flexibility of the modular concept can be explained with the structure of this concept. The absence of a fix conveyor system allows the duplication of single workstations, which therefore lowers the demand of assembly lines and personnel. This modularity in the production system has therefore also an effect of the cycle time.

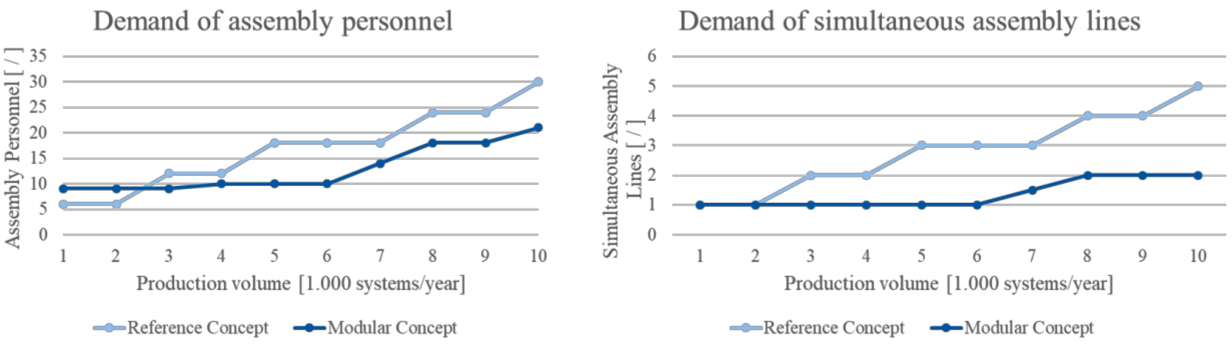

Figure 5: Demand of assembly personnel and simultaneous assembly lines in dependence of the annual production volume

Comparing the values calculated through MTM for a generic and simplified fuel cell system it must be stated that these time values are still far below the durations mentioned in the literature above. This can be justified by the fact that the system was simplified with a limited count for parts in the BoM. In addition, assumptions for the assembly tasks had to be made while applying MTM that can differ from practical handling in assembly. As well, the EoL-Testing is not included within this approach, which reduces the efforts of the considered processes. As mentioned in chapter 3.3, a short leakage test for the fluid conducting subsystems via sniffing probe is included at workstation 5, however it is not covering the whole spectrum of tests to be finally conducted for EoL.

5. Summary and Outlook

In this work, a scalable production concept, that was derived and further elaborated as a modular structured production system, where the assembly content is separated into a pre- and an end assembly. With the help of the methodology of MTM, the derived scalable production concept was at first transferred into a quantitative model that was afterwards compared to a reference model. The comparison showed the scalable concept therefore performed better regarding the examined parameters. It required less simultaneous assembly lines and less assembly personnel while generating the same output in production volume. The data on this topic, which could be used for evaluation, in combination with fuel cell system assembly is very limited. Therefore, values generated by this methodological approach still need to be validated by practical application and differ a lot from the time values that were discovered within the estimation by James et al and the Mercedes-Benz GLC F-Cell assembly.

Further research needs to be carried out regarding the accounting of learning effects through economies of scale when applying MTM by calculation of the time values of assembly contents within the pre-assembly, as the time values where assumed in this model to be static over the time dimension. Additional research can as well be conducted on further modularization [31] of the fuel cell system itself by approaches through design for assembly (DFA [32]), where the design gets adapted to the processes in assembly by engineering. As there were no hybrid structures of manual and automated assembly systems examined in this work, this should be a topic for further investigation. It was concluded that possible assembly tasks to involve automation can be located in tasks, where the stack with its high weight is moved or many screws can be mounted and screwed simultaneously. The subsequent EoL-Testing is an important step within the value chain of the fuel cell system production since it guarantees the quality and therefore needs to be further researched and developed [33]. Further research on optimization of cycle time balancing including mechanisms to enhance disassembly for possible defective parts discovered in EoL-Testing is necessary.

Acknowledgements

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Appendix

Table 1: Bill of Materials for the considered fuel cell system; components are distinguished between the station at which they are mounted and the module to which they belong

Station	Component	Module	Quantity
1	Housing	Stack	1
1	Media Distribution Unit	Stack	1
1	Sealing for Media Distribution Unit	Stack	6
1	Screws	Stack	20
2	Solenoid Valves	Anode	1
2	Hydrogen Pipe (incl. T-pieces)	Anode	7
2	Distributor Valve	Anode	1
2	Hydrogen Injector	Anode	1
2	Recirculation Blower	Anode	1
2	Purge Valve	Anode	1
2	Drain Valve	Anode	1
2	Demister	Anode	1
2	Bracket	Anode	2
2	Screws	Anode	20
2	Cable (Power)	Anode	1
2	Cable (Data)	Anode	6
2	Cable Ties	Anode	20
3	Sealing (Compressor/Turbocharger)	Cathode	4
3	Compressor/Turbocharger	Cathode	1
3	Power Distribution Unit	Electric	1
3	Fuel Cell Control Unit	Electric	1
3	Screws	Cathode/Electric	18
3	Cable (Power)	Electric	1
4	Air Inlet	Cathode	1
4	Air Outlet	Cathode	1
4	Pipe	Cathode	11
4	Resonator	Cathode	2
4	Air Filter	Cathode	2
4	T-piece	Cathode	2
4	Bypass Valve	Cathode	1
4	Air Intercooler	Cathode	1

4	Humidifier	Cathode	1
4	Demister	Cathode	2
4	Sealings	Cathode	18
4	Hose Clamps/Clips	Cathode	24
4	Bracket	Cathode	2
4	Screws	Cathode	28
4	Cable (Data)	Cathode	4
4	Cable Ties	Cathode	8
5	Cooling Hoses	Cooling	12
5	T-piece	Cooling	3
5	Hose Clamps/Clips	Cooling	25
5	Sealings	Cooling	23
5	Locking Valve	Cooling	1
5	Ion Exchanger	Cooling	1
5	Coolant Pump	Cooling	1
5	Control Valve	Cooling	1
5	3-way Valve	Cooling	1
5	Compensating Reservoir	Cooling	1
5	Cable (Power)	Cooling	1
5	Cable (Data)	Cooling	8
5	Cable Ties	Cooling	16
6	Cable (Power)	Electric	2
6	Cable (Data)	Electric	3
6	Screws	Electric	10
6	Cable Ties	Electric	36
		Total	370

Table 2: Example for determining TMU values with the MTM data map for manually joining of a generic pipe – component section (no usage of tools)

Description of motion sequence	Information relevant for time assignment	Code	Time value [TMU]	Time value [seconds]
Movement to the material commission and way back	Walking / 6 m	KA6	150	5.40
Grabbing and placing of pipe	Component < 1kg, loose placing / range of motion between 50 and 80 cm	AE3	70	2.52

Grabbing of component and joining with pipe	Component < 1kg, narrow placing	AF3	80	2.88
Visual control	Visual control	VA	15	0.54
Put workpiece aside	Component < 1kg, loose and approximate placing	AA3	50	1.80
Total	-	-	365	13.14

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Biography

Achim Kampker (*1976) is head of the chair “Production Engineering of E-Mobility Components” (PEM) of RWTH Aachen University and known for his co-development of the “StreetScooter” electric vehicle. Kampker also acts as member of the executive board of the “Fraunhofer Research Institution for Battery Cell Production FFB” in Münster. He is involved in various expert groups of the federal and state governments

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