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A Storage Module Evaluation for the Hydrogen Fuel Cell on Toy Design

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Abstract: *The problem of environmental pollution has become worse and worse as the demand for energy has grown. An important aim of modern science is a diligent search for non-polluting methods of energy production. The fuel cell is one of the most important power sources devised in the 21st century and has all the necessary characteristics for environmental protection. The technology is pollution-free and highly efficient, converting the chemical energy of hydrogen gas directly into electricity. The fuel cell can be regarded as a small-scale power plant. The flow of electricity will continue as long as there is a supply of hydrogen. At present the storage of hydrogen is the most important consideration and there is not much information about fuel cells readily available at this time. This study concerns the development of 'The Hydrogen Fuel Cell generates Electricity Module' and demonstrates this in the design and use of a toy. A systemized analysis of power operation using existing fuel cell products and a setup of 'The Hydrogen Fuel Cell generates Electricity Module' was made. The Taguchi Method was used to arrive at the best parameter combination between fuel cell and toy. The best combination of parameters obtained in this experiment provides a power line voltage of 3.0V. An assessment was made of the arrangement of a non-pressurized single fuel cell that will best suit the requirements for use in the toy whale used in this work. This will instill feelings of personal scientific accomplishment and give the toy making industry a new look at the same time. We hope this can be applied on a larger scale in the future to provide non-polluting power for many such applications.*

Keywords: Hydrogen-based Energy, Fuel-cell, Toy, Whale, Design, Taguchi Method

1. INTRODUCTION

After the first proton–exchange membrane fuel-cell powered vehicle was introduced in 1965, the commercial prospects of fuel cells have attracted the attention and capital of several enterprises. The development of alkaline fuel cells gradually attained maturity in the 1970-1980s and molten carbonate fuel cells were also developed [1-2]. The known fuel cells can be divided into six categories: the Proton Exchange Membrane (PEM); Direct-Methanol (DM); Alkaline; Phosphoric Acid (PA); Molten Carbonate (MC) and Solid Oxide (SO) Fuel Cells depending on the electrolyte used. The PEM and (DM) Fuel Cells both operate at room temperature, have similar properties and are feasible power sources for portable electrical equipment and home appliances [3]. The PEM Fuel Cell is superior to the (DM) Fuel Cell in being more energy efficient, uses Hydrogen as a fuel and there is no production of poisonous carbon monoxide. The (DM) Fuel Cell also requires fuel purification. The PEM Fuel Cell is easy to maintain, has a longer life and is more suitable for toys [4]. Fuel cells can be arranged in modules and this makes it easy to meet different power demands. There is a range of different business opportunities for fuel cells, such as power sources for 3C electronic devices, transportation facilities, small power generation for home use and larger sized power plants for communities. A recent development in Japan is the use of fuel cells in mobile charging stations for 3C products. It is anticipated that fuel cells will play an important role in the future [5-6].

The PEM Fuel Cell converts fuel chemical energy directly into electric power through an electrochemical reaction between Hydrogen and Oxygen without the need for any other energy conversion processes. This makes PEM a novel electric power generating process that has some distinct advantages: it is very suitable for portable power and vehicle power systems, and also as a small-sized power supply for home use]. The PEM Fuel Cell mainly comprises a thin proton exchange membrane as an electrolyte to transfer protons [7-9]. Taguchi's Method is a highly developed and

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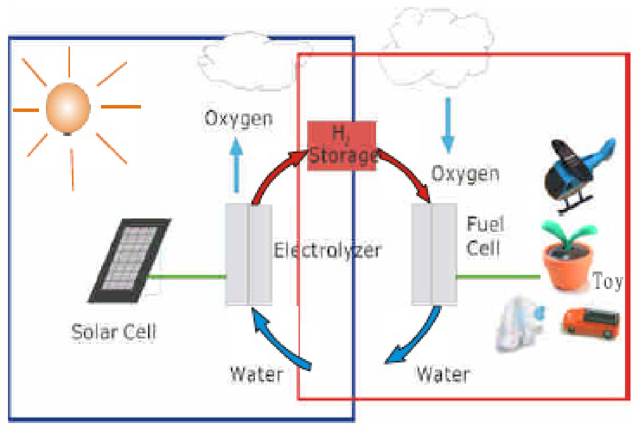

Figure 1. The fuel cell battery module and layout

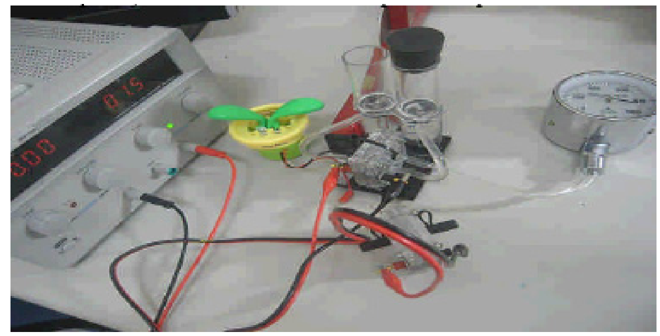

Figure 3. Experimental Module

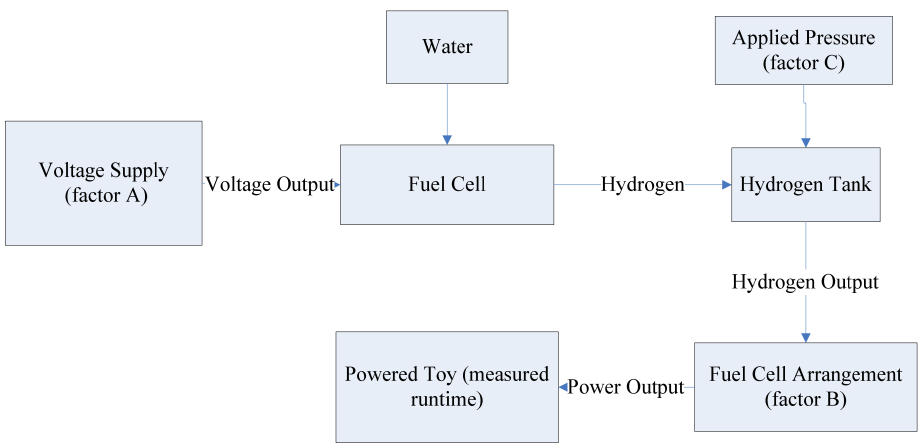

Figure 2. Diagram of Experimental Setup

disciplined scientific method for the evaluation and the implementation of improvements in products, processes, materials, equipment, and facilities. The method involves the optimization and selection of desired characteristics and a simultaneous rejection of the number of defects. This is done by a study of the key variables controlling the process and utilizing the procedures or designs that yield the best results [10].

The aim of this study is a combination of solar energy and PEMFC that provides a new and more convenient energy source for toys that is environmentally friendly and clean. The energy consumed by the fuel cell is "Hydrogen-based Energy", that relies on a conversion of the chemical energy of Hydrogen and Oxygen into electric power by the fuel cell. This principle is simple, highly efficient, has low noise and is non-polluting. If such a fuel cell is used in combination with the electric power from "solar energy" to electrolyze water and produce Hydrogen and Oxygen, this will be a "Hydrogen-based Energy" cycle. This renewable energy system module can provide a toy with a clean power source and can accomplish the circular use of "Hydrogen-based Energy". When solar radiation is available, the solar energy is effectively stored in the form of Hydrogen. In the absence of solar energy hydrogen based energy from the fuel cell will provide electric power through the "Proton Exchange Membrane Fuel Cell Power Supply and Work Module for Toys" allowing the continuous use of renewable energy.

2. RESEARCH METHOD

This research project uses the Taguchi Method to find the optimum design parameters and to develop a "Fuel cell battery module" that can be installed in the interactive toy built for this purpose. The goal is to achieve optimized efficiency with an environmentally friendly design. The investigation includes the design of two basic parts that include the system module, hydrogen power generator module and hydrogen storage module. The fuel cell battery module and layout is shown in Figure 1. The blue boxed area is the hydrogen power generator module where solar power is used to excite the fuel cell and transfer sufficient energy to water to generate the hydrogen required. The red-boxed area is the storage module for storing the generated hydrogen. The hydrogen produced will be converted into electricity to power the toy. This research focuses on the power generator and storage modules needed for the recycling of the reusable solar energy needed by this low powered toy.

This research makes use of three parameters, the generated voltages, fuel cell orientation and pressure. By controlling the voltage input to the 2113E proton exchange membrane fuel cell battery, water is split into hydrogen and oxygen and the hydrogen is directly stored in the tank. The Taguchi Method is used to analyze the correlation between the three parameters. As indicated in Figure 2 of the experimental setup, the variable voltage supplied (factor A) to the fuel cell for the electrolysis of water is configured to supply power for 1 minute and the hydrogen produced is stored in the hydrogen tank. Different numbers of fuel cell batteries are used to power the toy and their arrangement is also varied (factor B).

3. EXPERIMENTAL SETUP

The experiment was conducted using a 2-level orthogonal array to display the factors (the experimental module is shown in Figure 3). The average was derived from the results of five repeated experiments to obtain an indication of the quality and variations in the experiment procedure.

The Taguchi Method can effectively provide usable data from a reduced number of experiment repetitions. It is based on the orthogonal array and signal-to-noise ratio (S/N ratio) for an evaluation of the influence of the factors on the quality of the experiment. To set up the experiment, each factor and level is arranged orthogonally, according to the rule, to reduce the number of repetitions required. The S/N ratio is analyzed to obtain the optimal combination of factors and levels. The Taguchi Method is effective for the evaluation of the best runtime parameters for the "Hydrogen Fuel Cell Battery Module" on the hydrogen-powered toy whale model.

3.1. Control Factors and Levels

The experimental factors on runtime selected for this research include the voltage supply, battery arrangement, and initial hydrogen pressure in the tank. As can be seen in Table 1 three factors and two levels were selected for the experiment and arranged in an orthogonal array (Table 2).

3.2. Orthogonal Array

The three factors and two levels selected for the research were arranged orthogonally, according to the Taguchi Method $L_4(2^3)$, to conduct the experiment (Table 2). The control factors in Table 1

Table 1. Experimental control factors and level for the powered toy hydrogen fuel cell battery

Factor	Description	Level 1	Level 2
A	Voltage Supply	1.5V	3.0V
B	Battery Arrangement	Single	Two in series
C	Initial Tank Pressure	None	200mmAq

Table 2. $L_4(2^3)$ Orthogonal array (experimental factor arrangement)

Exp.	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 3. Orthogonal array for experiment factors

Factor Repetition	A. Voltage Supply	B. Battery Arrangement	C. Initial Tank Pressure
1	1.5V	Single	None
2	1.5V	Two in series	200mmAq
3	3.0V	Single	200mmAq
4	3.0V	Two in series	None

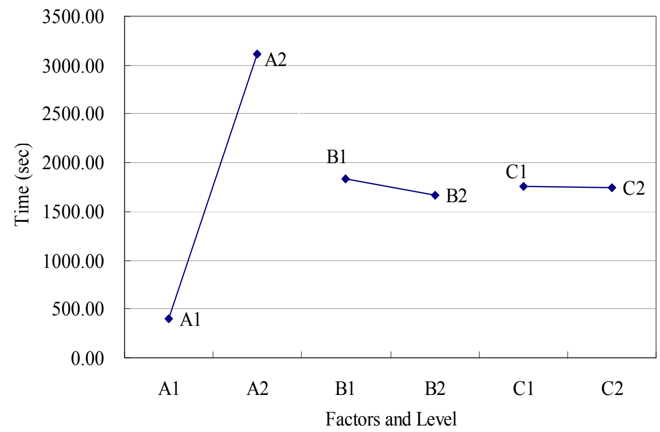

Figure 4. Quality indicator of the response factors

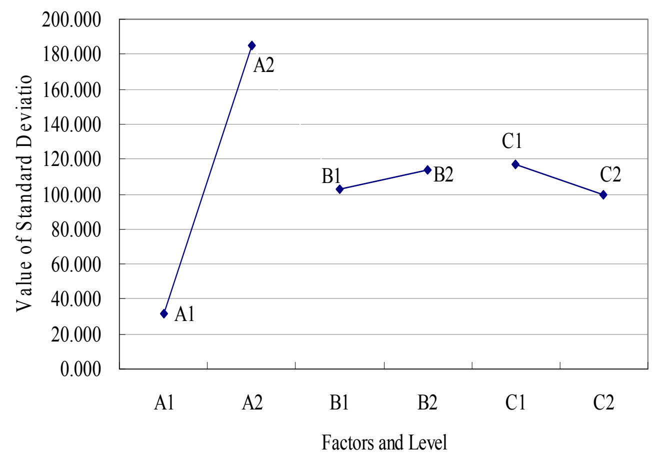

Figure 5. Standard deviation of the response factors

and levels in Table 2 were then combined as shown in Table 3.

3.3. Signal-to-Noise Ratio (S/N)

The goal of the research was to find the maximum runtime (t) for the toy and the higher the quality factor the closer the goal. In fact, a perfect quality indicator would have infinite value. The S/N ratio reflects both quality and minimum variance characteristics. Using the S/N ratio, we can find the optimum parameter combination.

4. RESULTS AND DISCUSSION

4.1. Results of Taguchi Analysis

4.1.1. Quality Factor Analysis

Since the goal of this work was to measure the runtime of the powered toy, the time for each individual module can be used to analyze the influence of each control factor on the quality of the entire module. In this experiment, the average runtime for each factor (Level 1, Level 2) on different levels (A, B, C) was plotted on the line chart (Figure 4). The quality reflected from each factor can be clearly seen and that for factor A has the greatest slope. This

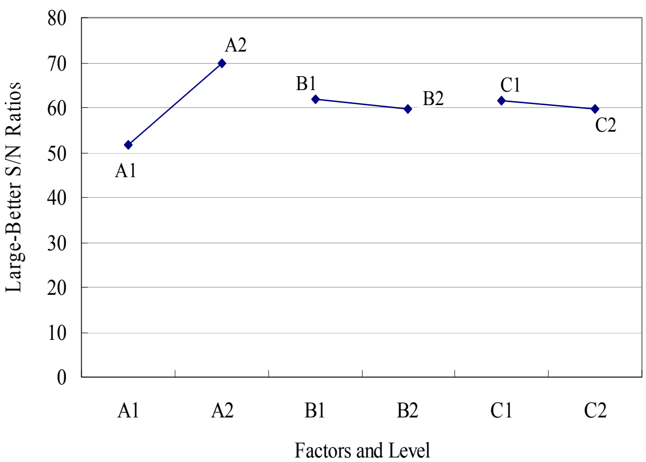

Figure 6. Signal-to-noise ratio of the response factors (maximized S/N ratio)

Figure 7. Hydrogen-powered toy whale

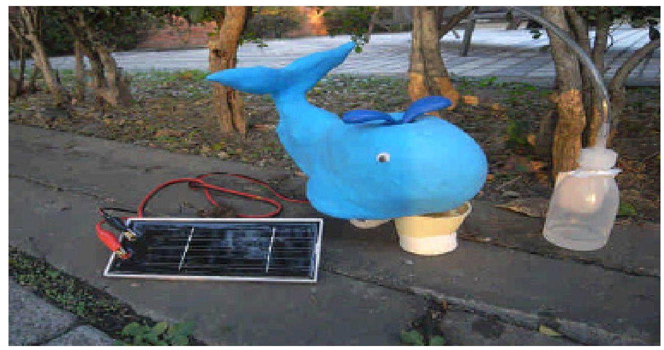

Figure 8. Exposing the panel to sunlight and refilling the toy with water

means that factor A (voltage supply) has the most significant influence on the quality. The data clearly indicate that a combination of A2B1C1 provides the highest quality.

4.1.2. Standard Deviation Factor Analysis

The standard deviation demonstrates the level of variance from each response factor (Figure 5). The standard deviation for each factor can be obtained from the line chart and the best combination is the one with lowest variance. The combination factor of A1B1C2 exhibits smaller variance and has the most stable quality.

4.1.3. Signal-to-noise Ratio (S/N) Analysis

The experimental data results show the best combination of factors to be A2B1C1 and A1B1C and since the goal is to obtain the greatest quality by "Maximizing the S/N ratio" this will also predict the optimum parameter combination. Figure 6 is the signal-to-noise ratio of the response factors (maximized S/N ratio). The best predicted combination factor is A2B1C1 as it has the best S/N ratio.

Table 4 shows a summary of quality indicators, standard deviation and signal-to-noise ratios. The A1B1C2 combination exhibits the most stable quality and the A2B1C1 combination the maximized quality indicator and S/N ratio.

Using the Taguchi Method to find the best parameter combination for the "Hydrogen Fuel Cell Battery Module" shows that a comparison between the experimental set and predicted values shows a variation of less than 5%. This is a clear indication that the experiment is feasible. The experiment verifies that the A2B1C1 combination exhibits the highest quality indicator, using a single 3.0V fuel cell battery and no applied pressure. The A1B1C2 combination was more stable even though it exhibited less runtime. The following conclusions can be made:

1. The most critical factor for the hydrogen production module is voltage. Significant variation in hydrogen production is seen between the 1.5V and 3.0V levels. In the case of this module, there is an approximately 600% difference in the uptime.
2. The comparison of a single fuel cell battery with two in series shows that the single fuel cell battery supports a longer runtime. The reason is that the fuel cell can be viewed as a power generator and batteries in series increase the current being drawn. Even though the powered toy will have better initial performance (more swinging movement), the runtime will be shorter, assuming that the amount of hydrogen consumed is fixed.
3. From the quality indicator it can be seen that variation of the pressure in the hydrogen tank does not exhibit significant influence on runtime. However, the experiment shows that the higher pressure provides more stable results.
4. A toy with reciprocating motion has been used as the experimental subject in this work because power consumption is low and it shows significant mechanical action. If the fuel cell battery is paired with a solar energy source, we can achieve near perpetual motion.

Table 4. Best parameter combination

Analysis Method	Best Parameter Combination
Quality indicator factor	A2B1C1
Standard deviation factor	A1B1C2
S/N ratio	A2B1C1

4.2. Implementing the Model

Paper clay was used to model the outer shell of this hydrogen powered toy whale. The internal mechanism fitted into the shell is comprised of adapted parts from modified solar-powered toys. The

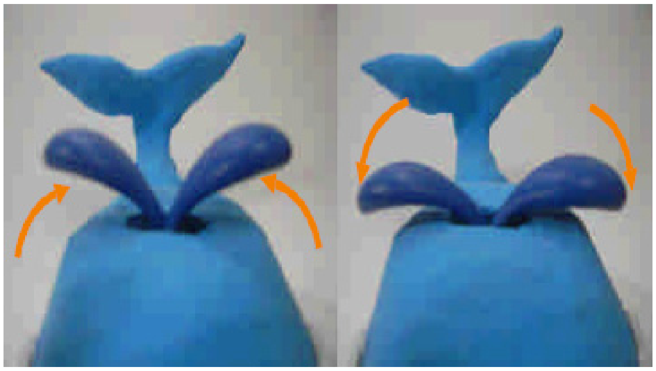

Figure 9. Mechanism and diagram for the water spraying action of the hydrogen-powered toy whale

"Hydrogen Fuel Cell Battery Module" from the previous section is also installed inside the shell. The toy model is shown in Figure 7.

The Taguchi Method was used to find the optimum combination of factors for the "Hydrogen Fuel Cell Battery Module," and applied in the design and construction of the hydrogen-powered toy whale shown in Figure 8. The system can be connected to an external solar power panel for the replenishment of the hydrogen fuel. When the toy is low in battery power, the hydrogen will supply continuous power to the toy for "refueling". When the water level becomes low it can be replenished through the intake. Figure 9 is the mechanism and diagram for the water spraying action of the hydrogen-powered toy whale.

5. CONCLUSIONS

An environmentally friendly hydrogen energy source is implemented using a "Hydrogen Fuel Cell Battery Module" design to power the "swing-action toy" constructed for this research. The runtime of this hydrogen-powered toy whale has been optimized. This experiment validates the hydrogen energy source as feasible for application in toy design. The Taguchi Method also shows that under a specific pressure, the fuel cell battery trends towards a more stable output. In order to extend the runtime of the powered toy and reduce the effect of weight loading, multiple fuel cell batteries should not be used because they cause excessive loading. The use of a single higher-powered fuel cell (higher output), lightens the load on the toy and simplifies hydrogen storage. This research not only effectively raises the commercial potential for hydrogen-powered toys, but also makes a contribution in the fields of academic science and environmental education.

6. ACKNOWLEDGEMENTS

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