Design of unmanned aerial vehicle mobile hydrogen refueling station

Gendi Li¹, Kuisheng Wang¹, Yong Liu² and Junbo Zhou*¹

¹College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing100029, China
²BeiJing CEI Technology Co., LTD, Beijing100071, China
*Corresponding author’s e-mail: zhogab@163.com

Abstract. Traditional unmanned aerial vehicle (UAV) that uses lithium batteries as a power source which limits UAV’s performance and application due to their short flying time. New UAVs which use hydrogen fuel cell as its power have longer flying time up to three times of traditional ones. The UAV mobile hydrogen refueling station has solved the problem of UAV’s energy, and it is a device that provides hydrogen as the power for a hydrogen fuel cell UAV. The process flow of the UAV mobile hydrogen refueling station is introduced. The way of pressurization has been innovated, and the pressurization process has been tested. The result shows that, increasing the pressure of the compressed gas and the inlet hydrogen can increase the output hydrogen flow. Meanwhile, in order to avoid pneumatic booster pump operating under high load for a long time, compressed gas pressure and inlet hydrogen pressure should also be properly controlled within a stable range. It has a certain guiding significance for the design of mobile hydrogen refueling station.

1. Introduction
Since the development of the unmanned aerial vehicle (UAV), it has been favored by people for its ability that performs high-performance operations in the air. With the growth of demand and the innovation of technology, China's civilian UAV will develop rapidly in the future. By 2023, the market turnover is expected to reach 96.8 billion yuan, with a growth rate of more than 60% annually. The market is considerable in the future[1]. However, the short flying time of UAV has been bothering users. Ordinary lithium-ion batteries can maintain the drone's flying time only about 20 minutes. The advent of hydrogen fuel cell has solved this problem very well. An UAV with a hydrogen fuel cell can maintain the flying time about 1 hour after refueling with hydrogen[2, 3, 4].

The development of hydrogen fuel cell UAV is subject to the construction of hydrogen refueling station, so it has become the focus how to inject hydrogen into hydrogen fuel cell UAV safely and efficiently. The workplace of UAV is uncertain, and the use of UAV is frequent, therefore, it is necessary to develop a mobile hydrogen refueling station which provides hydrogen energy for hydrogen fuel cell UAV according to the use of it. Compared to the stationary hydrogen refueling station, mobile hydrogen refueling station has small volume, low cost and large service radius, and it can meet the requirements of hydrogen fuel cell UAV. Tongji University built the first mobile hydrogen refueling station in China in October 2004. The HY-MBS-5k mobile hydrogen refueling station is developed by Heidelberg company, and it has a stable operation record; HyHauler series of mobile hydrogen refueling system greatly shorten the filling time which is developed by Quantum,
USA. Therefore, the mobile hydrogen refueling station has a good development prospect[5].

2. Process design of unmanned aerial vehicle mobile hydrogen refueling station

2.1. Electrolysis process

Hydrogen is produced by water electrolysis. The electrolysis process of unmanned aerial vehicle hydrogen refueling station is shown in figure 1. The core device for hydrogen production is PEM (proton exchange membrane) electrolyzer, the electrolysis unit consists of several anode and cathode chambers, the different polar chambers are separated by proton exchange membranes. When water is electrolyzed, water is decomposed into oxygen and hydrogen ions under the action of the anode catalyst, the hydrogen ions move to the cathode through the solid polymer electrolyte; the electrons and hydrogen ions combine to form hydrogen under the action of the cathode catalyst[6, 7]. The electrolytic equation of the anode is:

\[
2H_2O \rightarrow O_2 + 4H^+ + 4e
\]

The electrolytic equation of the cathode is:

\[
4e + 4H^+ \rightarrow 2H_2
\]

Heat is generated during electrolysis, according to long-term operational experience, the optimum operating temperature of the electrolyzer should be maintained at around 60ºC. Therefore, it is necessary to supply circulating water to the PEM electrolyzer continuously for heat exchanging. The circulating water should be deionized water, pump is used to supply circulating water to PEM electrolyzer, and the circulating water is cooled by heat exchanger, keeping the temperature of circulating water in PEM electrolyzer at about 60ºC.

Hydrogen is in a bubble shape when it escapes from the PEM electrolyzer, which will take away trace amounts of water. To meet the standard of hydrogen fuel cell, the water in the hydrogen needs to be removed to prevent the hydrogen from flooding the catalyst layer when entering the interior of the hydrogen fuel cell, thereby reducing the catalytic effect. The process flow is shown in figure 1. Firstly, the liquid water with large volume is separated from hydrogen through the first stage separation of gas-liquid separator; secondly, it is separated through a secondary separation stage of the condenser, reducing the saturated water content of hydrogen by lowering the temperature; finally, the moisture in hydrogen is removed by a pressure swing adsorption column, one tower dries and the other regenerates, hydrogen is adsorbed under high pressure and regenerated under normal pressure or vacuum. The dew point of hydrogen can reach -60ºC by adsorption, so that it can meet the hydrogen requirement for proton exchange membrane fuel cell.
2.2. Pressurization system improvement

The traditional pressurization process is shown in figure 2. The low-pressure hydrogen in the first-stage hydrogen storage container is pressurized to the second-stage hydrogen storage container through the pneumatic booster pump 1, and then, the hydrogen in the second-stage hydrogen storage container is pressurized again by the pneumatic booster pump 2, finally the hydrogen gas is injected into the hydrogen cylinder of the UAV. This pressurization method requires two pumps with a low boost ratio to achieve the purpose of high refueling pressure, but the pressurization method is complicated and cumbersome.

The improved pressurization process is shown in figure 3. The purified hydrogen is firstly stored in the first-stage hydrogen storage container, the hydrogen in the first-stage hydrogen storage container is compressed by the pneumatic booster pump to the second-stage hydrogen storage container, and the compression process stops when the storage pressure of the second-stage hydrogen storage container reaches the upper limit. Open the valve directly between the second-stage hydrogen storage container and the hydrogen cylinder of the UAV when refueling hydrogen cylinder of the drone. Firstly, the refueling process is carried out by pressure difference, it can save energy loss during the pressurization of hydrogen and shorten the time of hydrogen refueling. Then turn on the pneumatic booster pump after the pressure is balanced at both ends, and pressurize the hydrogen from the second-stage hydrogen storage container to the hydrogen cylinder of the UAV until the pressure in the hydrogen cylinder of the UAV reaches 35MPa. At present, 35MPa is the general refueling pressure value in China.

The innovation of this improvement is that, a pump with a large boost ratio is used instead of two pumps with a small boost ratio to achieve the effect of secondary pressurization. This pressurization method abandons the traditional way of using an electrically-driven compressor, but uses a pneumatic booster pump for supercharging. Pneumatic booster pump has small volume and high boost ratio, it uses compressed air as the power source to avoid the possibility of hydrogen coming into contact with electricity, it also improved the reliability of equipment and reduced the risk of equipment operation[8, 9]. This pressurization method is suitable for small integrated equipment.

![Figure 2. The traditional process of pressurization.](image-url)
3. Pressurization experiment

3.1. Experimental facility
The first-stage hydrogen storage container is used as the intake buffer device of the pressurization system, the volume is 20L, and the pressure high limit is set as 1MPa; the second-stage hydrogen storage container is used as a hydrogen storage device for the pressurization system, and the volume is 20L, the pressure high limit is set as 13MPa. The volume of the hydrogen cylinder of the UAV is 3.5L, and the pressure high limit is set as 35MPa. The pressure value is monitored by the pressure transmitter and the valves are pneumatic ball valves which open and close automatically, they are both centrally controlled by PLC.

3.2. Experimental scheme
Refueling the first-stage hydrogen storage container with hydrogen continuously, when the pressure reaches 1MPa, turn on the pneumatic booster pump and pressurize hydrogen into the second-stage hydrogen storage container. When the pressure of the first-stage hydrogen storage container drops to 0.6MPa, turn off the pneumatic booster pump and when the pressure rises to 1MPa, turn on the pneumatic booster pump. Repeat the steps until the pressure of the second-stage hydrogen storage container reaches 13MPa. And at this time, the hydrogen refueling process is performed. Firstly, open the valve between the second-stage hydrogen storage container and the hydrogen cylinder of the UAV, the refueling process is carried out by pressure difference. Then, turn on the pneumatic booster pump after the pressure is balanced at both ends, and pressurize the hydrogen from the second-stage hydrogen storage container into the hydrogen cylinder of the drone until the pressure reaches 35MPa.

Since the time of pressurizing hydrogen from the first-stage hydrogen storage container into the second-stage hydrogen storage container is determined by the amount of hydrogen production, only the refueling process for the hydrogen cylinder of the UAV is tested. In the first experiment, the pressure of compressed air source was adjusted to 6 bar, and the intake pressure of hydrogen was adjusted to 2, 3, 4, 5 bar respectively; in the second experiment, the pressure of the compressed air source was adjusted to 8 bar, and the intake pressure of hydrogen was adjusted to 2, 4, 6, 8 bar respectively.
3.3. Experimental results and discussion

Figure 4. The flow curve of pressurization process 1.

The flow curve of pressurization process 1 is shown in figure 4, the pressure of the compressed air source is stable at 6 bar, when the intake pressure of hydrogen is increased, the output flow rate of hydrogen is increased accordingly. The reason for this phenomenon is that the intake pressure of hydrogen is increased, then the amount of hydrogen stored in the high-pressure chamber is increased, so that the output flow of hydrogen is increased per unit time; comparing figure 4 with figure 5, when the intake pressure of hydrogen is 2 bar and 4 bar, the pressure of compressed air source is increased from 6 bar to 8 bar, and the output flow of hydrogen is increased accordingly. The process of pressure balance takes 7 seconds, after balancing, the pressure is 10.6MPa. It takes 15-20 minutes to pressurize the hydrogen from 10.6MPa to 35MPa. According to the experimental data, the output flow of pneumatic booster pump can be increased by increasing the pressure of compressed air source and hydrogen, but it also increases the load on the pump, it can be adjusted according to the user's requirements for hydrogen refueling.

Figure 5. The flow curve of pressurization process 2.

The flow curve of pressurization process 2 is shown in figure 5, the pressure of the compressed air source is stable at 8 bar, when the intake pressure of hydrogen is increased, the output flow rate of hydrogen is increased accordingly. The reason for this phenomenon is that the driving pressure is increased, then the piston of the pump moves faster, so that the output flow of hydrogen is increased per unit time.

The process of pressure balance takes 7 seconds, after balancing, the pressure is 10.6MPa. It takes 15-20 minutes to pressurize the hydrogen from 10.6MPa to 35MPa. According to the experimental data, the output flow of pneumatic booster pump can be increased by increasing the pressure of compressed air source and hydrogen, but it also increases the load on the pump, it can be adjusted according to the user's requirements for hydrogen refueling.

4. Conclusion

This paper designed the process flow for the UAV mobile hydrogen refueling station and improved the pressurization mode, the feasibility is verified.

1) The output flow rate of the pressurization system can be enhanced through increasing the pressure of compressed air source and hydrogen intake, but it will increase the energy consumption, users can change the variable value according to the actual situation during operation.

2) The UAV mobile hydrogen refueling station provides hydrogen energy for hydrogen fuel cell UAV, and hydrogen is stored and injected under high pressure, so that a whole set of hydrogen energy preparation, storage and refueling process have been realized. It has certain guiding significance for the design and commercial promotion of UAV mobile hydrogen refueling stations.

Acknowledgement

This research was supported by Beijing University of Chemical Technology and BeiJing CEI Technology Co., LTD.

Reference

[1] Kenzo N., (2007)Prospect and recent research & development for civil use autonomous unmanned aircraft as UAV and MAV.Journal of System Design and Dynamics, 2: 120-128.
[2] Xu WX, Zhang HG, Ma J, Gong ZY. (2019) Life cycle environment evaluation of hydrogen source system for fuel cell vehicles. IOP Conference Series: Earth and Environmental Science, 3: 8-15.

[3] Wang SH, Li SC. (2019) Design of high efficiency energy power system for hydrogen fuel cell cruise ship. IOP Conference Series: Earth and Environmental Science, 4: 2-3.

[4] Imanina N.H.N., Lu T.K., Fadhilah A.R. (2016) A proposed model of factors influencing hydrogen fuel cell vehicle acceptance[J]. IOP Conference Series: Earth and Environmental Science, 1: 2-3.

[5] Sun K., Pan X.M., Li Z.Y., Ma J.X. (2014) Risk analysis on mobile hydrogen refueling stations in Shanghai. International Journal of Hydrogen Energy, 35: 20411-20419.

[6] Choi P., Bessarabov D.G., Datta R. (2004) A simple model for solid polymer electrolyte (SPE) water electrolysis. Solid State Ionics, 1: 535-539.

[7] Wei G.Q., Wang Y.X., Huang C.D., Gao Q.J., Wang Z.T., Xu L. (2010) The stability of MEA in SPE water electrolysis for hydrogen production. International Journal of Hydrogen Energy, 9: 3951-3957.

[8] Yan S., Wu T.C., Cai M.L., Wang Y.X., Xu W.Q. (2016) Energy conversion characteristics of a hydropneumatic transformer in a sustainable-energy vehicle. Applied Energy, 171: 77-85.

[9] Du J.K., Liu Y.J., Feng X.Q. (2011) The pneumatic booster pump apply to the single wafer cleaning process. Equipment for Electronic Products Manufacturing, 1: 18-20.