Design of adaptive humidity control system based on ultrasonic humidification in room temperature

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Abstract. Humidity is an important parameter of ambient air. Humid air has a great influence on discharge and fuel combustion. In order to simulate a real humid environment for studying the effect of humidity on different experiment, based on ultrasonic humidification mechanism, an adaptive humidity control system is designed. The system can produce uniform wet air without liquid water. By self-adaptive control, humidity can reach the required value and keep stable. The response time and humidity accuracy is investigated. The results show that the system can provide uniform gaseous humid air. Its response time can be up to 2s. Control accuracy is up to ±2%RH. These works are significant and can be widely used for combustion and discharge.

1. Introduction
When the aircraft is in a high humidity environment, such as low altitude flight, coastal, high humidity weather or through clouds, the wet air in the aircraft’s engine contains both dry air and a large amount of gaseous water. Wet air will no longer be regarded as an ideal gas, and its thermophysical properties have changed greatly. At this time, the influence of humidity on engine thermal process can’t be ignored. The increase of atmospheric humidity will lead to the decrease of compressor stability margin and the increase of combustion instability. When the engine operating parameters remain unchanged, the increased humidity makes the air that flow into the engine decrease. The combustion state of the combustor will move to the lean flameout boundary. In addition, humidity changes the nature of the gas entering the combustor. The heat capacity of the gas increases. It will be more difficult for the air temperature to reach the required temperature for fuel combustion reaction. Therefore, when the environmental humidity changes greatly, it is very difficult to maintain stable combustion and reignite the aero-engine combustor[1].

For the discharge device, the humidity will change the experimental conditions dramatically. For example, in dielectric barrier discharge, discharge process and products are different at different humidity. Especially, if there are liquid water drops in air, it will affect the normal operation of the discharge device.

Therefore, it is very necessary to study a humid air control system to provide stable and free liquid water. In most of the studies on the influence of water on the experiment, the water/air ratio is used directly. However, in this condition, the water in the air includes both liquid water and gaseous water. Their influence mechanism is very different[2-3].

Humidity is an important environmental parameter. The main difficulties of simulating humidity environment are as follows. Firstly, it is very difficult to separate temperature and humidity. Secondly, the relative humidity of the air is different under different temperature conditions. Therefore, it is
difficult to make the relative humidity reach and stabilize at the experimental value. The conventional humidification method involves the heating and evaporation of liquid water. However, the vaporization of liquid water and condensation of gaseous water are very complicated\textsuperscript{[4-5]}. Thirdly, simulating environmental temperature and humidity requires very precise measuring sensor, equipment and control system. Fast natural condensation and impingement condensation of gaseous water will make the hygrometer not work\textsuperscript{[6]}.

In order to solve these problems, in this paper, based on the principle of ultrasonic humidification, a self-adaptive humidity control system is established to realize the uniform humid air without liquid water at room temperature.

2. Design of humidity system

2.1. Ultrasonic humidification principle
The ultrasonic humidification is a new technology to generate wet air. It is manly based on two simple physical processes: formation of small water droplets and natural vaporization of water droplets. By electronic over frequency (the oscillation frequency is over 1MHz), the high-frequency resonance of the ceramic plate can be made. As is shown in Fig. 2, when ceramic plate is under water and near the surface of water, liquid water can be thrown off the water surface by ceramic plate vibration. The liquid water is atomized into $1-5 \ \mu m$ ultrafine droplets. Then, these ultrafine droplets further diffuse into air to form water mist. After the formation of water mist, the contact area between water droplets and air is increased. Therefore, the natural vaporization process of water droplets is greatly accelerated. This method can be used for forming uniform wet air without liquid water. By ultrasonic humidification, the relative humidity of air can be improved without heating liquid water or adding chemical reagents.

2.2. Experimental system
The humidity control system mainly consists of dry air supply source, fan, humidification chamber, ceramic vibrator, humidity stabilization chamber, high-precision temperature meter, high-precision humidity meter, filtering device and control circuit, as shown in Fig. 2.

The temperature meter accuracy is $\pm 0.1 ^\circ C$, the resolution is $0.1 ^\circ C$. Its measurement range is $-40 ^\circ C \sim 85 ^\circ C$; The humidity meter accuracy is $\pm 1.5\%$ RH, the resolution is $0.1\%$ RH. Its measurement range is $0\sim100\%$ RH. The external sensor probe is installed. The humidity stabilization chamber is a square chamber of $600 mm \times 600 mm \times 600 mm$.

The control circuit of system generates $1.7MHz$ ultra-high frequency signal. Through the high-frequency resonance of the ceramic plate, the water is thrown away from the water surface to produce a naturally water mist. The water can be atomized into $1-5 \ \mu m$ ultrafine particles floating in the air without heating and changing the water temperature, accelerating the vaporization process of water and changing the humidity of the ambient gas. Though the fan, the dry and fast air flow from air supply source will slow down and spread evenly, pushing the wet air out to the outlet of the
humidification chamber. As the air flows through the filter, the larger droplets collide and condense on the strainer. Humidity stabilization chamber is used to stabilize the air flow and further accelerate the natural gasification of ultra-fine water droplets. When humid air flows out the humidity stabilization chamber, it becomes uniform and wet air without liquid water. The humidity stabilization chamber is relatively large and is built with the glass material with better heat transfer. This ensures that the moist air absorbs the heat outside the humidity stabilization chamber to compensate for the temperature drop caused by the natural evaporation of water particles. Thus, the temperature of the wet air is always kept at room temperature. Temperature meter and humidity meter monitor the temperature and humidity of humidification chamber and humidity stabilization chamber. The temperature and humidity values are transmitted to the control circuit for processing and real-time display.

Figure 2. Humidity control system.

2.3. Control principle

The control principle is shown in Fig.3. When the system works, the control circuit always monitors the outlet temperature and relative humidity though the temperature meter and humidity meter. When a certain required humidity value is set up, the control circuit turn on. Humidification chamber start to generate wet air. Air flow gets into humidity stabilization chamber. Air relative humidity continues to increase. Once the control circuit recognizes that the actual humidity value is about to reach the set value, the humidification circuit switch will automatically close. When the circuit detects that the actual humidity value drops and is about to reach the set value, the humidification circuit switch is opened in advance.
3. Results and analysis
For the designed system, the control effect under different air flow was tested. Under the air flow rate of 300L / min and 500L / min, we simulated the humidity environment without liquid water. Under the two flow conditions, the control error of humidity is ±2% RH. The shortest response time is within 2S.

4. Conclusions
An unheating method was investigated to humidify air. The control circuit realize adaptive humidity adjustment. Based on ultrasonic humidification mechanism, an adaptive humidity control system is designed. Its humidified effects, response time and control accuracy were studied in this paper. Main conclusions are as follows.
(1) The system can produce uniform wet air without liquid water and keep at the room temperature.
(2) By self-adaptive control, humidity can reach the required value and keep stable. The response time and humidity accuracy is investigated. The system’s response time can be up to 2s. Control accuracy is up to ±2%RH.

These works are significant. It can be widely used for combustion and discharge.

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References
[1] M. G. De Giorgi, E. Pescini, S. Campilongo, G. Ciccarella, D. Fontanarosa, A. Ficarella, J. Eng. Gas Turb. Power 141, 10(2019)
[2] Y. P. Li, G. H. Niu, X. Wang, J. Tang, Y. X. Duan, Plasma Chem. Plasma P. 38, 20(2018)
[3] A. A. Abdelaziz, H. H. Kim, J. Phys. D Appl. Phys. 53, 114001(2020)
[4] E. J. Oerter, M. Singleton, M. Thaw, M. L. Davisson, Rapid Commun. Mass SP. 33, 8(2019)
[5] Paulauskas R., Martuzevicius D., Patel R. B., Pelders, J. E. H., S. Nijdam, N. Dam, M. Tichonovas, N. Strigas, K. Zakarauskas, Exp. Therm. Fluid Sci., 118, 110166 (2020)
[6] C. Tiebe, M. Detjens, U. Banach, T. Hubert, TM-TECH. MESS. 85,8(2018)