UPDATES IN

nozzle-less ultrasonic coating technology

FOR FUEL CELL MANUFACTURING

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Improvements in coating deposition control can be achieved with advanced ultrasonic coating technology that provides precise control of the coating pattern and film thickness

Considerable effort is ongoing to improve the efficiency and reduce the manufacturing costs of hydrogen fuel cells. Much of the attention has been focused on the cell stack, specifically the catalyst-coated membrane and the gas diffusion layers.[1][2][3] Numerous coatings are used in the cell stack, many of which need to be applied in thin layers. Examples of these coatings include copolymers, solvents, and suspensions containing various combinations of solvents and carbon, ceramics, platinum, palladium, and other precious metals. An efficient means to apply thin layers of these materials is an important cost driver. [1] Additionally, the performance of the fuel cell can be improved if the coating layer is applied uniformly and without defects.

The precise application of these coatings to substrates in thin layers presents many challenges with the application method and material handling. Some of these challenges include the ability to apply a uniform, thin layer of coating, consistency of the coating application device, and changing coating material properties.

Coatings need to be applied to each element of the fuel cell assembly including the anode, cathode, electrolyte, carbon paper layers, etc. Typically, the coating needs to be applied in successive thin layers to achieve the desired thickness, texture and electrical properties. Some of the coating application methods currently used are dip coating, air atomizing spray nozzles, ultrasonic spray nozzles, screen printers, manual brushing, and "nozzle-less" ultrasonic spray heads.

There are many limitations with traditional coating methods for the application of coatings used in fuel cells. With dip coating techniques, it is difficult to control both thickness and uniformity. Air atomizing spray valves produce overspray, have a tendency to clog easily, produce a non-uniform spray pattern and have difficulty maintaining accurate control of the liquid flow rate. Ultrasonic spray nozzles produce a softer, more efficient spray but produce non-uniform coating layers due to difficulties with control of the spray pattern shape and inability to precisely start and stop the liquid spray. Screen printing techniques are best suited to applying thick coating layers and have very limited ability to apply thin layers. Manual brushing techniques are inherently subjective because of the dependence on operator skills.

There are also difficulties with material handling for coatings used in fuel cells. Many of the coatings are suspensions, which have a tendency to separate or "fall out" quickly. This condition causes the coating properties to change over time, which further limits the ability to apply a uniform coating layer to the substrate.

An automated method for the precise application of fuel cell coating materials has been developed that utilizes a "nozzle-less" ultrasonic spray head and a precision X-Y-Z-q-Æ motion control platform with advanced material handling capabilities. The ultrasonic spray head uses ultrasonic energy to break the liquid into small drops to form the spray however the liquid does not pass through the device. Liquid is applied externally to a solid surface, which is vibrating at an ultrasonic frequency (>20kHz). Directed air streams are used to expand or focus the ultrasonically produced spray, providing a rectangular, uniform spray pattern. The liquid flow and airflow to the spray head are electronically controlled, providing complete control of the spray pattern shape and velocity. The coating system incorporates advanced liquid delivery systems to ensure that the coating liquid properties remain consistent during the coating process. The "nozzle-less" ultrasonic spray technology is widely used for applying various coatings in the electronic assembly industry. [4][5]

This paper considers a particular advancement in thin film application of fuel cell coatings using the "nozzle-less" ultrasonic spray head known as ultra-spray technology with the integrated fluid delivery applicator and X-Y-Z-q-Æ motion control platform.

Ultra-spray head with integrated fluid delivery system

The ultra-spray head with integrated fluid delivery system (IFDS) consists of an ultrasonic transducer with a spray

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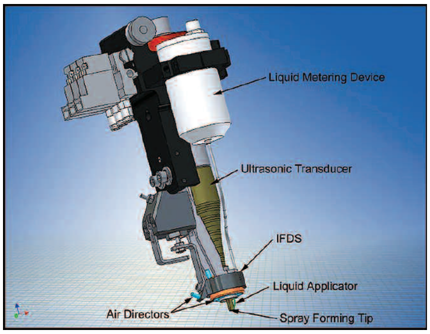
forming tip, an ultrasonic generator, an external liquid applicator, a precision liquid delivery system and air directors.

The ultrasonic transducer contains a spray-forming tip that vibrates at an ultrasonic frequency (> 20 kHz). The ultrasonic transducer is resonant at a particular ultrasonic frequency of 35 kHz, 45 kHz, or 60 kHz and is driven by an ultrasonic generator with a corresponding frequency. The particular ultrasonic frequency is selected based upon the material to be sprayed and the coating application requirements. In general, a lower frequency ultrasonic transducer is capable of spraying a higher viscosity liquid and producing higher flow rates. The amplitude of vibration of the spray-forming tip is also set with the ultrasonic generator. The amplitude is adjusted so that the particular coating material can be atomized for the required flow rate range. Some coatings require greater amplitude or more ultrasonic energy to properly atomize and some coatings require less. The ultrasonic frequency and amplitude are analogous to a loud speaker producing a single note. The frequency is the pitch of the note and the amplitude is the volume. An ultrasonic frequency of 35 kHz is optimal for most suspensions used in the manufacture of fuel cells. The amplitude of vibration of the spray-forming tip is then adjusted to accommodate the required flow rate range.

The coating liquid is delivered to the spray-forming tip on the ultrasonic transducer with an external liquid applicator. The liquid is stored in a pressurized reservoir and fed to the liquid applicator with a precision liquid delivery system. The ultrasonic vibrations of the spray-forming tip break up the liquid into small drops and propel them from the tip in the form of a spray. The spray produced with ultrasonic energy alone is a very low velocity, narrow "sheet-like" pattern. The width of the spray pattern produced is equal to the width of the spray-forming tip (2 mm to 4 mm).



Ultra-spray head with integrated fluid delivery system.

Air directors are used to produce air streams to shape and accelerate the ultrasonically produced spray. Two distinct spray patterns are produced with the directed air streams: narrow and wide. An air-shaping ring in the IFDS assembly is used for the narrow mode operation of the spray head. The air-shaping ring entrains the ultrasonically produced spray without mixing with it and produces a coating segment about 5 mm wide with well-defined edges from a distance of approximately 25 mm between the spray head tip and the substrate. An air director in the IFDS assembly is used to produce the wide mode. The air director impinges a jet of air on tip of the spray head opposite the liquid feed side. The resulting airflow entrains and expands the ultrasonically produced spray to produce a flat (rectilinear) pattern up to 5 times the width of the pattern produced in the narrow mode. The width of the spray pattern is proportional to the distance between the spray head tip and the substrate. The wide mode is optimal for the application of most of the suspensions used in the manufacture of fuel cells because it produces the thinnest possible coating.

Since the spray is produced with ultrasonic energy rather than pressure and because a low velocity air stream is used only to shape the spray, the transfer efficiency is in the range of 95 to 99 percent. In other words, very little coating is wasted due to overspray.

All process parameters for the ultra-spray head with Integrated Fluid Delivery System are set electronically including liquid flow rate, air pressure, spray mode (wide or narrow), head height, and head speed.

Liquid delivery and material handling systems

A variety of liquid delivery and material handling methods are required due to the large variety of coatings used in the manufacture of fuel cells. The materials used include various suspensions, solutions and solvents, each with their own unique handling and application requirements.

The method used to deliver the coating liquid to the liquid applicator on the ultrasonic spray head is based on the properties of the coating. The coating material is typically stored in a sealed reservoir and then precisely metered to the liquid applicator. Liquid metering methods include: pressurizing the coating reservoir, activating liquid flow with a solenoid valve and delivering the liquid to the applicator through a precision orifice; pressurizing the coating reservoir and delivering the liquid to the applicator with a rapidly pulsing solenoid valve; delivering the liquid to the applicator with a motorized positive displacement piston type pump; or additional metering methods can be utilized as required.

Suspensions typically require agitation within the reservoir to maintain consistent properties. Additionally, recirculation of these suspensions is also required to prevent the material from settling in the coating delivery lines.

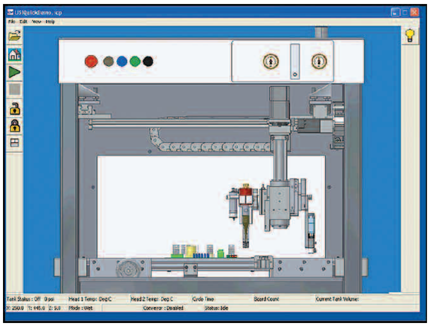
Motion and Positioning Platform

One or two ultra-spray heads are mounted to a precision X-Y-Z-q-Æ motion and positioning system. The system is controlled with a Windows XP based operating system utilizing an integrated PCI motion controller. A graphical user interface (GUI) is used to set all operating parameters and cre-

X-Y-Z-q-Æ System Platform

ate process programs. The GUI employs a graphical image of the entire coating system platform with "hot spots" for each subsystem. The system operator uses a trackball to highlight each hot spot and bring up a window to setup or configure each subsystem. Hot spot windows include the X-Y-Z-q-Æ gantry system, the coating head setup, the system conveyor and coating program recipe.

The X-Y-Z-q-Æ gantry system window allows the head(s) to be moved manually with the trackball anywhere throughout the range of motion within the system.



System Platform GUI

The coating head setup window allows all parameters of each coating head to be manually activated. This is primarily used for the initial setup of each coating head and to ensure that the coating heads are functioning properly.

The conveyor window is used to set the operating parameters of the conveyor for automatic operation with other equipment upstream and downstream as well as to test the various conveyor functions.

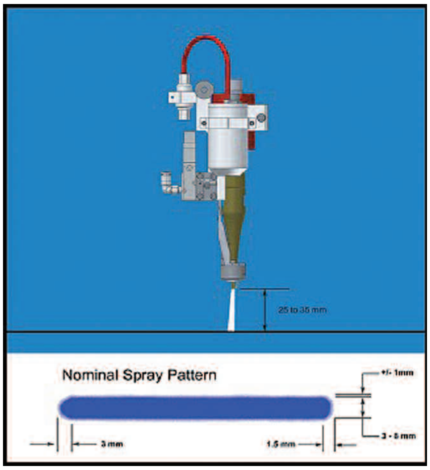
The program recipe window is used to develop a coating recipe for a specific coating material and substrate. "Teaching" the coat areas with a simple point and click operation creates the program recipe. All critical process parameters are set with the coating recipe including: liquid flow rate; air director pressure; spray mode (narrow or wide); head position; head speed; head height; head tilt or no tilt; and head rotation angle.

Performance Characteristics

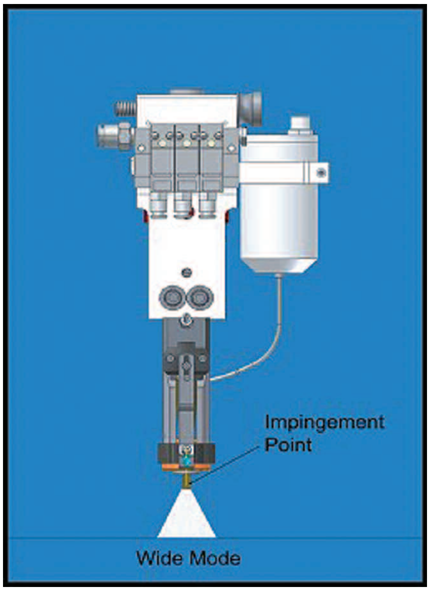
The dual mode ultra-spray head can be used to operate in narrow mode or wide mode.

Narrow Mode – the spray head produces a 5 mm wide coating deposition at a height of 25 to 35 mm between the spray head tip and the substrate. As shown in the figure, the edges of the coating pattern are well defined on the order of ± 1 mm. The narrow mode is primarily used for materials that are solutions and is not typically used for suspensions.

Wide Mode – the spray head produces a pattern width proportional to the height of the spray head. The pattern width increases as the distance between the spray head tip and the substrate increases. The wide mode is idea for suspensions and for applying very thin coating layers. Coating layers from sub-micron to several microns are achievable when operating in wide mode.



Narrow mode



Wide mode

Example of fuel cell coating application

The following is a representative example to illustrate a typical fuel cell coating process. The material used, deposition procedure and results are genuine. However, the specific material formulation, details on the substrate and process objectives cannot be disclosed due to confidentiality agreements with the fuel cell manufacturers.

REQUIREMENTS

Coating Material: water-based suspension containing metalized carbon particles mixed in the range of 10 to 25 percent solids.

Substrate: Mylar sheet. Mylar is used to illustrate the coating process and coating deposition results. The actual substrates used are proprietary to the specific fuel cell manufacturer.

Deposition Requirements: Dry deposition density in the range of 0.005 to 0.1 mg/mm2. The resulting coating must be free of pinholes, uniform, homogeneous and have a smooth texture.

APPLICATION PROCESS

System Platform: Prism 350 with 90-degree head rotate.

Coating Head: 35 kHz ultra-spray IFDS Head operating in wide mode.

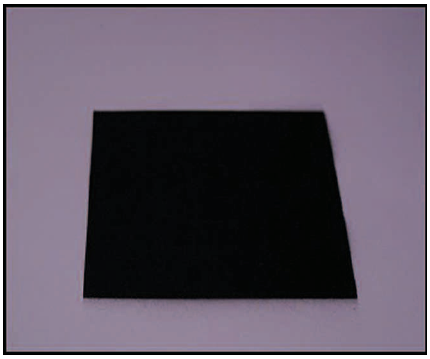
Application Process: Thin layers of coating applied in successive interwoven, criss-cross patterns. Each layer is applied at a deposition density of approximately 0.002 to -0.005 mg/mm2.

RESULTS

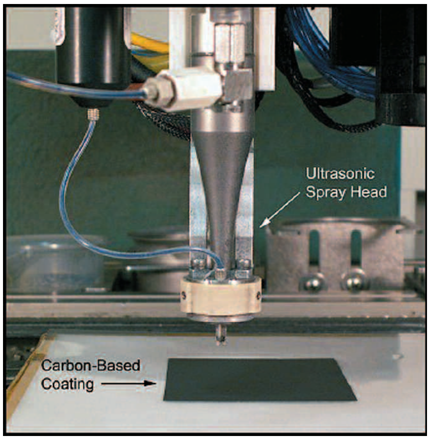
Deposition Density: 0.005 to 0.1 mg/mm2 (depending upon flow rate settings and number of layers applied)

Surface Appearance: Smooth, defect free coating with a uniformity of better than ± 5 percent.

Transfer efficiency: A transfer efficiency of 95 to 99 percent is verified by the weight of dry coating on the substrate when compared with the amount metered through the spray head.



Mylar substrate coated with carbon-based metalized suspension.



35 kHz ultra-spray IFDS head.

Conclusion

The requirement to improve fuel cell efficiency and reduce costs is increasing the need for a precise method to apply thin layers of various coatings in the manufacturing process. The combination of the nozzle-free ultra-spray head and a precision, liquid handling and delivery system and a sophisticated X-Y-Z-q-Æ head motion and positioning platform is a significant improvement over conventional application techniques.

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