

## GAS DELIVERY FOR PLASMA SPRAY COATING APPLICATIONS

### PROBLEM

Feed gas or gas mixture flow rates play a determining role in the quality of the film coatings that can be achieved using plasma spray coating processes. As a consequence, accurate, precise and repeatable control of the flow rates is critical for successful and repeatable plasma spray processes.

Traditionally, the control of gas delivery in plasma spray processing has been based on volumetric flow measurement and control using rotameters. This approach is strongly affected by variations in the pressure and temperature of the source gas, and it can result in non-repeatable processes.

This Application Note discusses the use of more accurate electronic mass flow control for gas delivery in plasma spray coating applications.

### BACKGROUND

#### Plasma Spray Technology

Many functional coatings of industrial importance are deposited using plasma spray coating technology (Figure 1).

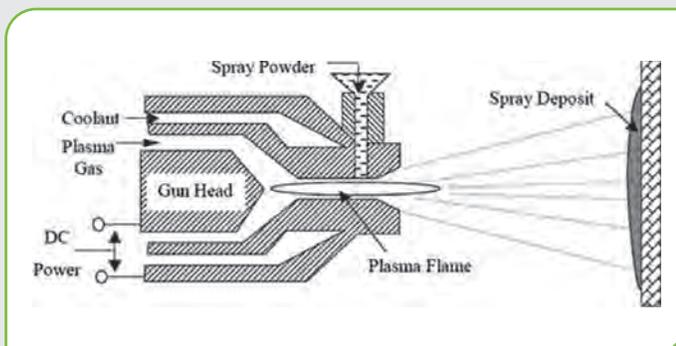


Figure 1a - Schematic of a plasma torch configuration that uses a powder material source [1] [2]

The automotive, aerospace and industrial fabrication industries use this technology to provide:

- Corrosion protection
- Wear resistance
- Clearance control
- Heat & Oxidation resistance
- Temperature management
- Electrical resistivity and conductivity

Plasma sprayed materials range from metals to refractory ceramics and include:

- Carbides
- Ceramics
- Metallics
- Abradables

Plasma spraying uses plasma as a heat source to melt a precursor material for deposition. Temperatures at the center of the plasma within the torch are over 8000°K at atmospheric pressure [3].



Figure 1b - Photo of a plasma coating operation [1] [2]

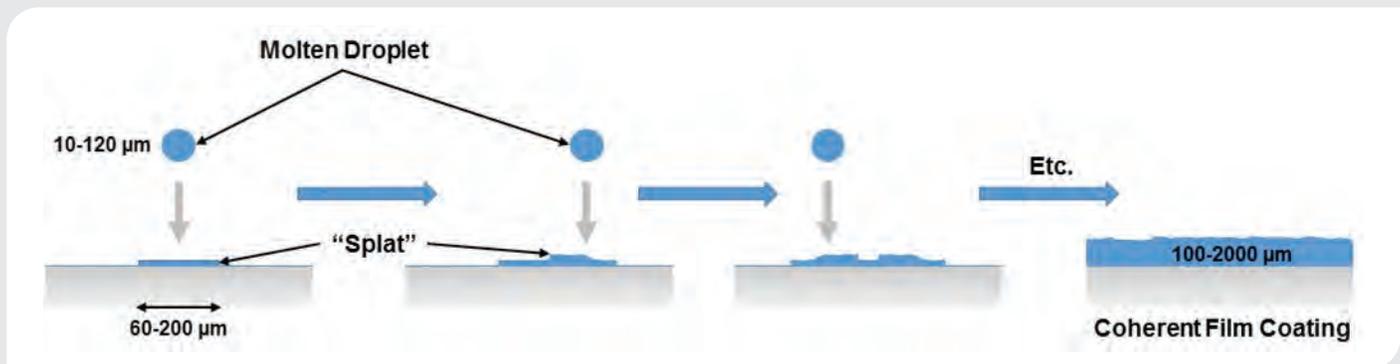


Figure 2 - Basic principle of plasma spray coating [1]

Materials can be introduced to the plasma as powders, (Figure 1a); plasma spray systems also introduce the deposited material as a consumable wire cathode or from a liquid source). The powder melts, producing fine ( $\mu\text{m}$  size) droplets of molten deposition material that are conveyed to the substrate by the carrier (plasma) gas. There, they deposit on the substrate surface as solid “splats”. As these “splats” accumulate, they eventually coalesce to form a coherent film coating (Figure 2). While adherent films are the most common product of plasma spray coating, standing parts can also be produced through post-deposition removal of the substrate.

Commercial DC arc plasma guns are simple in design (Figure 1b). They consist of a water-cooled chamber and hollow front nozzle (anode) with an orifice. Contained within the hollow anode and concentric with the orifice in the front nozzle is another electrode (cathode), also water-cooled. The cathode is non-consumable, fashioned from thoriated tungsten, a material resistant to evaporation under the conditions of temperature and pressure that exist within the torch.

In operation, a high pressure plasma gas or gas mixture (e.g. argon or argon/oxidant mixtures) is fed to the torch where a high frequency spark ignites the plasma between the cathode and anode. Temperatures at the center of the plasma are as high as  $10000^{\circ}\text{K}$ . The high pressure gas flowing through the torch body and out the orifice both maintains the plasma and confines it,

keeping the outer layer of the plasma at temperatures low enough to avoid thermal damage to the nozzle bore.

A large number of equipment and process parameters influence the interaction of the particles with the plasma jet and the substrate and, thus, the deposit properties. These include feedstock type, plasma gas flow rate and composition, energy input, torch offset distance, substrate cooling and other secondary influences.

### Gas Flow Control in Plasma Spray Operations

Precise control of the gas flow rate is important to the success of plasma spray operations. The flow rate influences both the molten deposition material droplet size and the droplet velocity and these parameters are critical determinants of the final physical properties of the deposited film. Thus, reliable plasma spray processes require an effective tool for delivering accurate, precise and repeatable gas flows to the plasma torch.

Historically, gas flow to plasma spray torches has been controlled using rotameters, Figure 3, in which gas delivery is measured as volumetric flow. Rotameters must be mounted vertically with the smallest diameter end of the tube in the lower position.

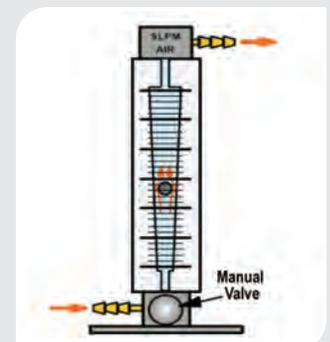


Figure 3a - Schematic of a conventional flowmeter [3]

The force of the gas flow lifts the float; as the float rises in the tapered tube, more gas can pass around the float.

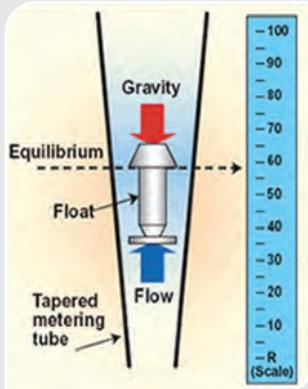


Figure 3b - Schematic of the flow tube, float and measurement scale showing the interplay of forces due to gravity and flow [3]

The equilibrium vertical position of the float is determined by the balance between flow force and gravity. A vertical scale is calibrated to read the gas flow for a given tube taper and float density. The range of a rotameter can be changed by changing the density of float. Lighter floats rise to the maximum tube height under lower gas flow than do heavier ones.

While rotameters are mechanically robust and relatively simple to use, they are strongly affected by variations in the temperature and pressure of the supply gas. These conditions must be separately measured and accounted for to obtain accurate and precise rotameter measurements. Rotameters cannot be automated for data capture; the only possibility for data recording lies in manual observations by the operator. This makes them ill-suited for use in automated processes that employ modern control schemes. The accuracy of rotameters is typically between 3 and 5% of Full Scale with repeatability of ca. 0.25% of Full Scale.

Electronic thermal mass flow meters (MFMs) and mass flow controllers (MFCs) are superior to rotameters in measurement precision and accuracy and in flow stability. As well, their electronic sensing modality and digital electronics make them usable as control components in modern process control protocols.

## SOLUTION

MKS Instruments' thermal MFCs (Figure 4), unlike rotameters, measure gas flow as molar mass flow rate rather than volumetric flow rate. This approach provides a direct measure of mass flow, uninfluenced by variations in the backing gas temperature and pressure.



Figure 4 - MKS IP66-rated Mass Flow Controller (IE1000A)

MKS Instruments' IP66-rated MFCs are waterproof and dustproof. They are rated for use in harsh environments where ingress of dust and liquids is a problem and hose-down of the instrument may be required, including the less than pristine environments typical of many industrial plasma spray operations. The MFCs are manufactured in a clean room environment and all wetted materials are 316L stainless steel, ensuring contaminant-free gas delivery.

The design of the instrument hardware and firmware guarantees insensitivity to the temperature and pressure variations that might be encountered in the gas supply of a typical plasma spray processes. This makes the instruments simple to deploy with no ancillary measurements and compensations needed. Available as elastomer or metal-sealed MFCs, they incorporate advanced digital flow control electronics and a patented thermal sensor and mechanical design that ensures 1% of set point accuracy and repeatability of 0.3% of the gas flow reading. The accuracy and precision of the flow measurement, coupled with the highly repeatable control ensures that plasma spray processes using IP66-rated MFCs are tightly controlled and that these processes can be replicated with relative ease.

IP66-rated MFCs are available in a variety of communication interfaces including Profibus, Analog and 4-20 mA. In addition, MFCs can be operated via ModBus TCP/ IP via the Ethernet port located on all MFCs. They are designed as multi-gas/multi-range instruments, allowing users to change the gas type (e.g., between Ar, N<sub>2</sub>, O<sub>2</sub> and CO<sub>2</sub>) or Full Scale flow range (250-1000 slm) in <45 seconds using an on-board Ethernet interface and an integrated, JAVA-enabled web browser that requires no special software. This latter characteristic is especially valuable for reducing inventory burdens.

## CONCLUSION

Accurate, precise and repeatable gas flow control is a prerequisite for successful plasma spray coating processes. The most effective way to achieve such control is through the use of electronic thermal mass flow controllers. MKS IP66-rated MFCs provide just such an advanced solution for mass flow control of gases in plasma spray processing. They are both waterproof and dustproof and can be washed down to maintain cleanliness. Their manufacture and materials of construction eliminate contaminants in the gas delivery path. Flow control using the IP66-rated MFCs has state-of-the-art accuracy and repeatability that guarantees process transferability. The multi-range/multi-gas character of these MFCs enables rapid process adaptability and low inventory costs. These characteristics make the MKS Instruments' IP66-rated MFCs an ideal solution for the gas flow control requirements in most plasma spray coating processes.

## References

- [1] The plasma torch image was taken from the ASME website: <http://fuelcellscience.asmedigitalcollection.asme.org/article.aspx?articleid=1472368>.
- [2] [http://en.wikipedia.org/wiki/Thermal\\_spraying](http://en.wikipedia.org/wiki/Thermal_spraying)
- [3] P. Fauchais, "Understanding plasma spraying", J. Phys. D: Appl. Phys., 37, R86-R108, 2004.
- [4] Matheson Gas Co., Flow Measurement and Control – Rotameters, <https://www.mathesongas.com/pdfs/products/flowmeter-product-line-overview.pdf>