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FLOW CONTROL:
A NOVEL USE FOR POROUS METAL

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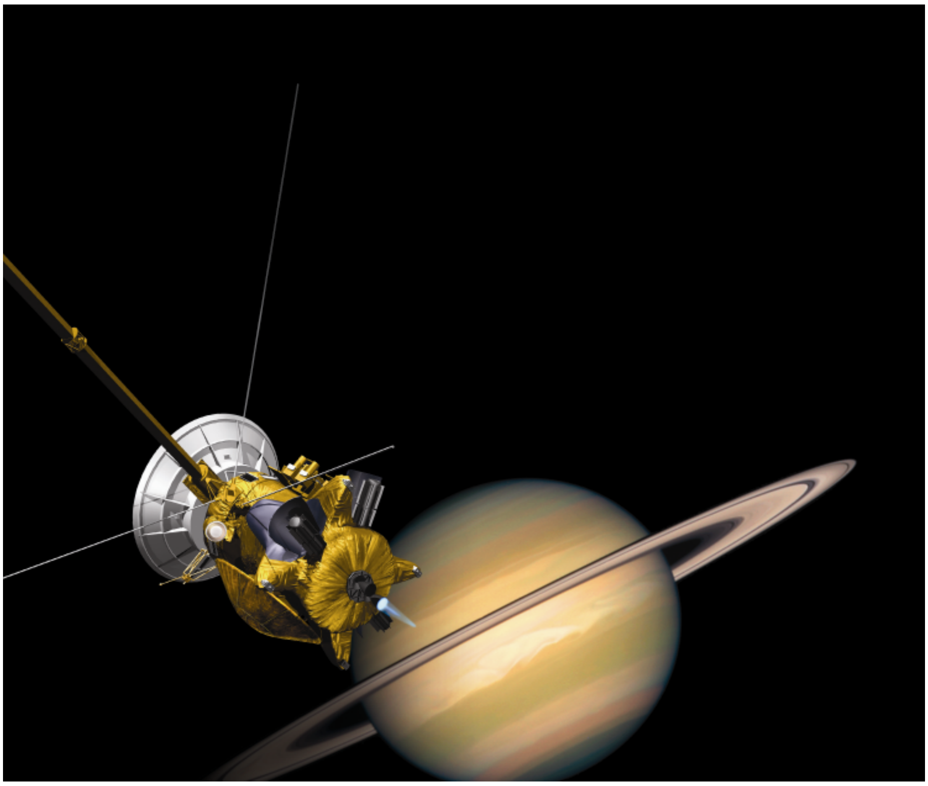
Published in issue of
Machine Design Magazine

October 11, 2007

NASA and the Jet Propulsion Laboratory require precise control of the gas metered into the positioning thrusters used on space probes. One such probe is the successful mission of the Cassini space probe as it traveled more than 2.2 billion miles to reach Saturn where it entered into its current 4-year mission (74 exploratory orbits around Saturn) to investigate the many intriguing mysteries of Saturn, its rings and its moons. Since first observed by Galileo some 400 years ago, scientists have sought to study the complex and diverse nature of the Saturn system.

At these immense distances, minute navigational control is critical to ensure that the probe maintains its intended course. In the case of the Cassini space probe, the thrusters - which NASA employs to maintain three-axis stability, control spin, execute minor interplanetary trajectory correction maneuvers and orbit trim maneuvers - are fed a discrete volume of compressed monopropellant hydrazine at a precise flow rate and time through flow controllers. This gas flow rate must be well known, precise and consistent as the probe travels for more than 10 years through space.

When NASA and the European Space Agency sought a robust approach to control gas metered to the thrusters used on Cassini and other space probes, they turned to Mott Corporation for their proven flow control technology. The heart of the flow control is a precision sintered porous metal element that is designed, fabricated and calibrated using unique processes to ensure uniform porosity and superior performance allowing greater flow consistency and accuracy. Mott is a world leader in the design and production of flow restrictors, utilizing almost 50 years of sintered porous metal experience.



Artist’s view of the Cassini space probe approaching Saturn.

What is a Flow Restrictor

This space probe application is but one of a myriad of unique and mission critical applications for static flow control devices, commonly called flow restrictors, which employ sintered porous metal media. Flow restrictors are static devices meaning there are no moving or adjustable components as one would find in dynamic flow control devices such as mass flow controllers or micro-metering valves. Precision porous metal flow restrictors are reliable, cost-effective alternative to other static flow control devices (like orifices and capillaries) and dynamic flow control devices. A porous metal flow restrictor is, in effect, a multiple orifice device with a myriad (usually 100's) of small pores, thereby creating a vast array of flow pathways.

Competing static technology include single orifices and capillary tubes which have limitations in accuracy and capabilities to fabricate holes of a precise diameter required for a given flow rate, especially when these holes can be as small as 0.010 inch or less for low gas flow rates. They are also sensitive to the presence of any particulate matter in the gas stream that could deposit in the orifice, thereby adversely altering the original gas flow rate versus pressure drop characteristics. Porous media consist of a myriad of small pores and often operate at a high differential pressure; thus a limited deposition of particulate matter potentially found in the fluid will have negligible affect on the overall gas flow rate versus pressure drop characteristics.

Basically a flow restrictor, as illustrated, consists of a precision porous metal element permanently inserted into a bore – located in a variety of standard industrial gas line fittings or application specific customized hardware. In operation, the porous metal element meters or limits the uniform flow of fluid (usually a gas) from high pressure to low pressure in a controlled manner. To obtain a desired flow rate, both the upstream and downstream pressure conditions must be maintained.

A flow restrictor is not a pressure control device (directly) and not a differential pressure controlling device (directly), but rather a flow control device for given pressure conditions. A flow restrictor will meter fluid flow, with high accuracy and repeatability, at prescribed upstream and downstream pressure conditions or limit gas flow, if a catastrophic process device failure should occur or inadvertent venting (opening) of a critical process gas line.

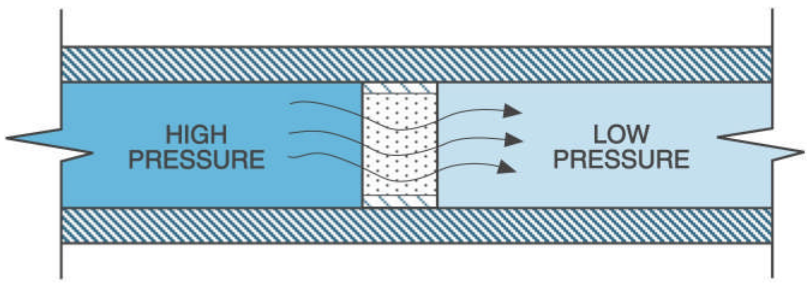
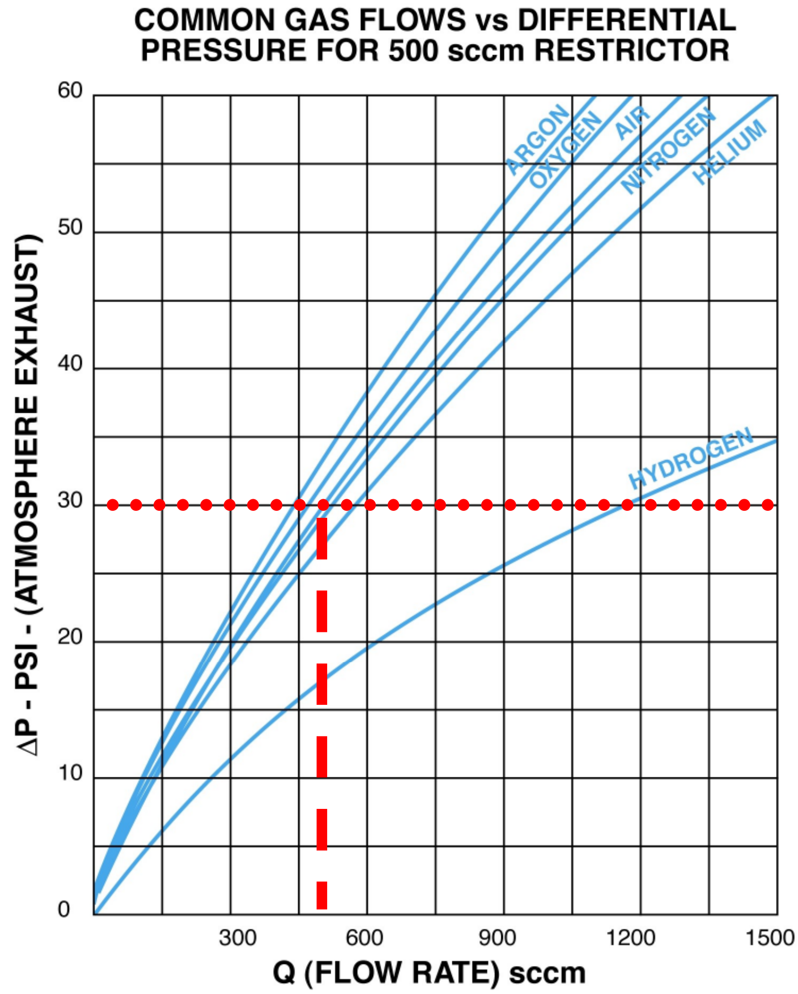


Illustration of a flow restrictor showing the location of the porous metal element and the resulting characteristics of the fluid stream.



Typical gas flow rate versus pressure drop curves for porous metal flow restrictors showing the effect of different gas compositions.

Fluid flow rate versus pressure drop curves monotonically increase with increasing flow rate and differential pressure drop across a flow restrictor. This flow rate versus pressure drop curve is dependent on a number of fluid properties including gas composition, temperature, upstream and downstream pressures. Porous metal element properties including diameter and thickness of the porous metal element and the porosity, pore size and tortuosity of the interconnected pores in the porous element also affect control of the fluid flow. For a given restrictor application where these parameters are known and controllable, the gas flow rate versus pressure drop characteristic is known and therefore will provide a consistent gas flow rate for a given pressure drop. For example, as showed on the attached set of flow characteristics curves, a flow rate of air at 500 sccm at a gas temperature of 70^{o} F can be achieved at an upstream gas pressure of 30 psig and a downstream pressure at atmospheric conditions.

The characteristic flow curve, as illustrated, is distinct and unique for each gas composition and set of system operating conditions. Differences primarily result from variations in gas viscosity and molecular weight and secondarily from gas compressibility factors and slip flow effects. The shape of the flow curves, from a fluid mechanics viewpoint, is dependent on the system pressures and flow rates, the gas flow regimes and gas compressibility.

While capabilities have been developed to measure flow restrictor performance, Mott possesses the capability to design and predict the performance of its flow restrictors in a vast array of operating conditions. The restrictor flow predictive model accounts for the non-linear relationship between pressure drop and flow rate by incorporating the basic fundamental equations to account for gas flow regimes (laminar, turbulent and slip flow), gas compressibility, gas properties (viscosity, molecular weight, compressibility factors) and accounts for complex size and shape of pores in porous media.

Sintered Metal Powder Technology

Sintered porous metal media and products are widely used for industrial filtration and fluid control applications found in the chemical process, petrochemical, aerospace, medical, pharmaceuticals, semiconductor industries and for OEM products. These media - made from various metal alloy powders to meet demanding application requirements - are manufactured in a controlled process by pressing pre-alloyed powder of controlled size and shape into discs, cups, bushings, tubes or porous sheet, followed by high temperature sintering.

Sintered metal media are offered in a wide range of media grades with mean flow pores ranging in size from 0.1 to 100 μm. The combination of powder size and shape, pressing pressure, and sintering conditions defines the pore size distribution, strength, and permeability of the porous media.

The development of specially designed and engineered sintered porous metal media - with a stable porous matrix, precise bubble point specifications, close thickness tolerances, and uniformity of permeability - assures reliable performance and long on-stream service life. The sintered metal powder media are available in different alloys including 316L stainless steel; Hastelloy® B, C-22, C276, N and X; Inconel® 600, 625, and 690; Monel® 400; nickel 200; alloy 20 and titanium to handle wide-ranging corrosion, temperature and pressure environments.

The proper selection of porous media with appropriate pore size, strength and corrosion resistance enables long-term filter operation with high efficiency particle retention in demanding filtration applications: high temperature, high pressure and corrosive fluids. The primary benefits of sintered metal media are: strength and fracture toughness, high pressure and temperature capabilities, high thermal shock resistance, corrosion resistance, cleanability, all-welded or sinter-bonded assembly, and long service life.

Applications

Today's OEM seek flow control solutions for ever more demanding applications requiring greater precision, less product variability and a low cost. The wide array of existing applications for flow restrictors include:

-gas flow control in breathing apparatus;
-safety devices on anesthesia equipment;
-gas flow control – either metering or flow limiting - on complex manufacturing equipment, e.g., semiconductor manufacturing equipment;
-gas flow splitting, balancing or mixing;
-gas flow control of instrument gases including gas chromatographs;
-gas mixing into beverages;
-controlled (calibrated) leaks for leak detecting equipment.

As part of the manufacturing process, each restrictor is individually calibrated – using NIST traceable instrumentation - for flow rate and pressure drop based on the designed condition using the application gas or an equivalent condition.

Porous metal restrictors can manage gas flow rates from less than <<1 sccm to greater than 40,000 sccm at pressure drops ranging from inches of water to 1000's psi and system gas pressure conditions ranging from full vacuum to 1000's psi. Gas temperatures are only limited by application-imposed limitations. Flow restrictors are suitable for a wide variety of gases ranging from inert to corrosive gases, where material capability is the limiting factor.

The gas flow rate versus pressure drop characteristics are set for a given restrictor; however, an infinite combination of specific flow rate versus pressure drop points (within min / max limits) can be achieved through proper selection of diameter and thickness of the porous media element and control of the porosity and size of the tortuous gas flow passages through the sinter porous media.

Restrictors are primarily fabricated from 316L stainless steel; however, in special cases, other alloys are available for more demanding applications. Principal applications criteria are that no corrosion or significant buildup of contaminates are allowable, thereby ensuring the integrity of the porous media and thus the unique gas flow rate versus pressure drop characteristics of a given restrictor.

Appropriate restrictor sizing requires knowledge of the following design specifications:

- -Design flow rate
- -Upstream pressure
- -Downstream pressures
- -Temperature
- -Gas composition
- -Hardware configuration (gas fittings or custom hardware)

Flow restrictors are a low-cost and yet robust and reliable choice to meter or limit fluid flow. Benefits of porous metal restrictors include multiple flow paths that resist plugging and improve their repeatability and accuracy, a compact size and tamper-proof design with no moving parts and maintenance requirements, materials that are corrosion resistant, and a manufacturing process that individually calibrates each restrictor at its designed operating condition.

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