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Going With the Flow

BY HANK HOGAN

Mass flow controllers (MFCs) carefully meter out gas, but they don't operate in a vacuum—in more ways than one. MFCs are part of a gas delivery chain of components subject to technological challenges and economic forces. This is particularly true in the large and demanding semiconductor market where a typical gas delivery system has a half dozen or more elements between the gas source and processing chamber. These include an isolation valve, a regulator, a pressure transducer, a filter, an MFC, and usually at least two other valves.

That chain isn't cheap and is replicated over and over again. Almost every module in a processing tool has an associated and relatively expensive gas panel. This conventional gas delivery system is the subject of industry-wide scrutiny.

"Simplifications of that delivery scheme are, I think, on everybody's roadmap," observes Christopher Case, chief technology officer for semiconductor process materials, equipment and services specialist for BOC Edwards (Crawley, UK).

For mass flow controllers, there are several developments that reflect these simplification efforts. Three are particularly important. The first is the impending arrival of pressure insensitive MFCs. The second is the use of digital intelligence to trim the number of different MFC part designations. The third is the use of all-nitrogen calibration schemes.

However, there's also a factor working against this drive to do more for less. MFCs face new demands due to the implementation of new processes, such as those involving the use of liquid precursors. These trends are evident in products from such companies as MKS Instruments Inc. (Andover, MA), Hampton, Teledyne Hastings Instruments (Hampton, VA), Mykrolis Corp. (Billerica, MA)., Celerity Group, Inc. (Milpitas, CA) and Qualiflow, S.A. (Montpellier, France).

No Pressure

As for the first trend, MFC manufacturers are under pressure to ignore pressure. This is due to the typical semiconductor gas delivery system. The components are there to deliver the right amount of a gas to the right tool without adding any particulates or contaminants. Traditional mass flow controllers accomplish their part by sampling the gas as it flows by. MFCs are closed-loop systems and the devices make adjustments so that the total flow holds to a set point. Unfortunately, the measurement methods react to changes in both flow and pressure. The latter can fluctuate as tools cycle through process recipes. That is why regulators are placed in the delivery chain. The semiconductor industry wants to eliminate these regulators by enhancing the design and operation of mass flow controllers.

> **"Processes require insensitivity of the MFCS to pressure perturbations upstream and downstream of the MFC." Kaveh Zarkar,**

"Processes require insensitivity of the MFCS to pressure perturbations upstream and downstream of the MFC. This feature will help the optimization and simplification of the gas delivery system while helping with the process uniformity and repeatability," explains Kaveh Zarkar, vice president and general manager for the material delivery group of MKS Instruments.

A pressure insensitive MFC can be built a number of different ways. One is by incorporating some sort of pressure sensing into the MFC itself. This can be done without increasing the size of the flow controller or its cost to customers. Another approach is to alter the design of the internal guts of the MFC so that the flow measurement becomes less sensitive to pressure fluctuations. Whatever the approach, several vendors have either announced or are about to announce pressure insensitive devices. Some of these products are already in beta trials with key customers and vendors expect to be able to ship devices in volume by early 2003.

The development of pressure insensitive MFCs has reportedly led to a number of benefits. The new MFCs are said to respond faster to changing conditions and to hold their set points better. Such gains, if they hold true in widespread deployment, should lead to better overall process control and repeatability.

The other benefit expected to appear with the new devices is economic. According to Celerity's senior vice president Joseph Foster, the company's new pressure insensitive MFCs should allow the cost of gas delivery systems to be reduced due to the elimination of components. Unlike better process control, the impact here is easy to estimate. Foster figures that some 10 to 15 percent of the entire cost of the system is tied up in components that are there simply to guard MFCs from pressure transients.

Flow controllers, like these from Mykrolis, are increasingly digital. That improves capabilities and cuts down on the different types required.

"You can change the input pressure to the device in a broad range, and the output characteristics are unaffected. So now there's no need for $1,000 worth of hardware on every stick," he notes.

Less is Digitally More

The second large trend is the addition of digital intelligence to flow controllers. The actual flow measurements are still analog in nature, as are all real world readings. However, these are now being immediately converted to digitized values. Once that is done, the manipulation of measurements and the flow control itself are all handled by digital circuitry.

This is markedly different from the situation that prevailed in the past. At that time, maintaining the flow at a set point was done by specialized circuitry; flow controllers would be calibrated for and manufactured to specific gases and flow regimens. Thus, a given flow controller might be able to handle high-flow nitrogen applications but would be useless for low-flow oxygen situations. One result was flow controller proliferation. The combinations of different flow rates and various gases lead to a welter of flow controller types.

The addition of digital intelligence and industry-standard control protocols to MFCs has changed that. Algorithms are now in software and easily updated, as opposed to being in either unchanging hardware or in hard to reach logic. Now one of today's flow controllers can do the work of multiple past MFCs.

"Theoretically, with one digitally controlled mass flow controller you can replace up to seven to ten [analog] mass flow controllers," says Jean-Pierre Liebaut, president and CEO of Qualiflow.

Manufacturers have been using this technology to cut the number of devices needed in a processing facility. For example Celerity's Foster says a modern semiconductor facility would, in the past, require 2,000 different MFCs. These would have to be manufactured by the vendor and stored. When an MFC failed in the field, maintenance personnel would have to pull it and replace it with one out of inventory. The proliferation of part types meant that simply tracking and stocking inventory was an expensive and time consuming proposition, and the plethora of part numbers had an adverse financial impact on virtually every aspect of the MFC life cycle.

For manufacturers, that has changed due to the incorporation of digital intelligence into mass flow controllers. In Celerity's case, this was also accompanied by a rethinking of the entire product line. The result has been a reduction of the unique part numbers from a figure in the thousands to one that can almost be counted on the fingers of both hands.

"We can now cover 85 percent of that with nine part numbers, and the balance can be covered with about another five or six configurations," comments Celerity's Foster.

Not a Drop in the Bucket

There is another development which has the potential to boost the operational efficiency and cost effectiveness of

An Open Approach

While MFCs are closed-loop systems, there are other approaches to flow control and gas distribution. An example is the flowPoint™ open-loop system from Applied Precision LLC (Issaquah, WA). Rick Loya is worldwide sales manager for the company's micropositioning and precision flow control products. According to Loya, the flowPoint product was originally developed at the request of a semiconductor equipment manufacturer as a replacement for manual metering valves.

In an MFC, part of the flow is diverted and measured. This can be done through a pressure drop or by sensing thermal conductance. This is then translated back into a flow and compared to a set point. The comparison indicates which way the device should move a plunger, diaphragm or other control element. In this way, a given flow rate is achieved and maintained.

In an open-loop system, precise positioning puts the actuator at the right place. There is no check of the actual flow. Loya likens the difference between the two approaches as two different ways to get from one place to another.

"You're driving your car, and you get feedback from the speedometer that says you're going X. Well, that's one way to do it. The other way to do that would be to know that if your gas pedal was to press half way, you would always get a certain speed," he says.

Such open-loop systems can be used to distribute gas throughout a plenum or manifold, such as might be found in a processing area in a tool. According to Loya, the advantage of this approach is that it is simpler: no sensor is involved. Another claimed advantage is that the system is immune to the feedback loops that an alternative solution, dual MFCs, can fall prey to.

"Theoretically, with one digitally controlled mass flow controller you can replace up to seven to ten [analog] mass flow controllers."
Jean-Pierre Liebaut

MFCs. During setup and calibration, a flow controller's performance is checked by running a gas through it. Ideally, this would be done with a relatively inert and benign gas that was inexpensive and widely available. Nitrogen fits that bill. Again, ideally, such calibration would be done using a single gas. So there's a push to nitrogen-only calibration, with the use of various conversion factors to account for the actual gas an MFC will be called upon to control. But this ideal has to contend with a rather imperfect world. The scheme depends, for one thing, on accurate conversion from measured nitrogen flow to the flow of the gas actually being metered out.

"Sometimes those conversion factors are not very good," notes Jack Martinez, a senior scientist in the office of microelectronics programs at the Gaithersburg, Maryland-based, National Institute of Standards and Technology (NIST). Part of NIST's work, according to Martinez, is to help vendors develop these conversion algorithms.

MFCs face new demands due to the implementation of new processes.

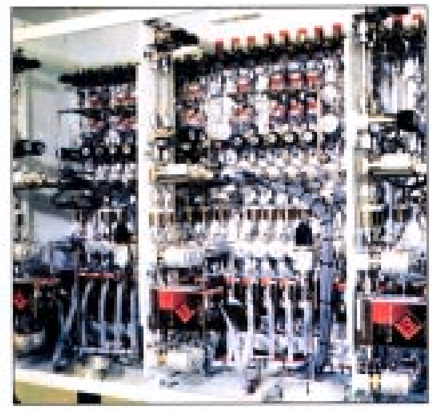
Pressure insensitive and intelligent MFCs that are calibrated using only nitrogen show promise of better and less expensive performance. That's a good thing because mass flow controllers face some new challenges in the semiconductor and other manufacturing arenas. One of these is due to the introduction of new processes, such as those that depend on liquid precursors.

As the name implies, liquid precursor manufacturing takes a liquid, converts it into a low-pressure gas, and then uses the reactant to create a desired film. Such films have electrical characteristics that are vitally important for the next generation of semiconductor devices. A number of new, ad-vanced semiconductor manufacturing processes take this approach to create materials of different capacitance.

However, these gases, created by liquid precursor methods, flow with very low pressure and may or may not have liquid droplets in them. Jim McAndrew, electronic research and development manager at Air Liquide, notes that such attributes present a challenge to, among other things, mass flow controllers.

"If you have a droplet coming thorough, that's always going to give you a higher contamination level. The other thing is, droplets may play havoc with, for example, mass flow controllers," he says.

Although it will be some time before the industry has to confront this issue in volume, there are a number of possible approaches to solving these problems.



Mass flow controllers from Celerity, such as the ones pictured above, will soon offer new features such as pressure insensitivity."

For instance, inline filters or precise heater control could eliminate droplets. The impact of such solutions on flow controllers is hard to predict. However, one thing is clear. Liquid precursor processes are likely to play a vital role in future semiconductor manufacturing, and so MFCs will have to adapt and go with the technological flow.

A Layer at a Time

While not a mass flow controller phenomenon, atomic layer deposition (ALD) is a challenge to flow controllers. ALD is a process of growing interest and commercial importance where a few, or perhaps only one, layer of molecules is deposited at a time. Applications involving atomic layer deposition can be found in both the semiconductor and data storage industries. As semiconductor processing sizes shrink, the need to create a thin, high quality film may lead to the increased use of ALD.

Because of the nature of the process, mass flow, and hence mass flow controllers, are not involved. However, some of the innovations developed for ALD might impact MFCs and vice versa. Qualiflow, for example, touts its piezoelectric valve technology. The company licensed this from Siemens and has introduced it into its MFC line because of the resulting simplification in the controlling valve.

"The big advantage is that you get rid of coils," asserts Qualiflow's Liebaut.

However, piezoelectric valves are also 20 to 50 times faster than the competing, coil-laden technology. That speed could make the approach ideal for ALD because atomic layer deposition demands greater speed from flow controllers. A conventional MFC may need to make flow adjustments once or a few times a second which does not suit the speed called for by ALD.