Technical Article

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Increase Vacuum Processing Throughput and Yield Using Advanced Downstream Pressure Control Methods

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ABSTRACT

Vacuum process tool throughput and yield rates can be significantly affected by the performance level of chamber pressure control. Faster step transitions and more precise pressure control are often desired or needed to enhance tool productivity or increase production yields.

Nor-Cal Products makes this technology available in its Intellisys™ product line. The technology revolves around a new method of operating a variety of stepper motor driven downstream control valves (such as butterfly, poppet, gate and pendulum). In essence, it combines closed loop stepper motor control with an advanced pressure control algorithm allowing such valves to be controlled in ways never before possible. As a result of the exceptionally fast valve actuation and ultra-high position resolution, throughput increases up to 15% coupled with significant yield improvements and 100-fold scrap reduction have been realized saving vacuum processors millions of dollars per year.

This paper covers a description of the closed loop motor control technology that makes the enhanced valve actuation possible followed by a parametric comparison of different downstream pressure control methods.

THROTTLE VALVES AND CONTROL SYSTEMS

One common method of controlling pressure in vacuum chambers is downstream pressure control. Downstream pressure control generally works well over a wide range of conditions, but its effectiveness can be challenged by "external" factors such as the sudden changing of inlet gas flowrates or the turning on or off of plasma events. Furthermore, certain flow-and-pressure combinations can force the throttle valve to operate in a position at or beyond the limit of its intended control range. In such instances neither accurate nor repeatable pressure control may be feasible. Alternatively, pressure control may be feasible but not in a fast and efficient manner. As a result semiconductor wafer yield and throughput suffer.

Existing Technology – At present, throttle valves are available from a host of manufacturers and tool OEMs. As different as the various valves may be, almost all possess one common characteristic – that they are driven by stepper motors. Conventional motor drive technology involves sequencing the stepper motor through a prescribed combination of motor winding currents designed to guide the motor to move in a given direction using the desired number of steps. Referring to Table 1, we can see a typical sequence for a bipolar full step moving sequence.

Table 1: Bipolar Full Step Phase Sequencing

STEP	A	A'	B	B'
1	+	-	-	+
2	-	+	-	+
3	-	+	+	-
4	+	-	+	-
1	+	-	-	+

From any given position (step), the motor can be moved to an adjacent position by changing the current going to the four respective drive phases (A, A', B and B'). Knowledge about the actual position is in these cases done by incrementing a step- or pulse-counter. This is referred to as open-loop motor control. Unfortunately, the speed and resultant position accuracy with which conventional open-loop stepping can be done is negatively influenced by non-linear effects from the valve and the motor drive assembly. Examples of such effects include inertia, friction, and backlash. As a result (and in comparison to what it could be) open-loop motor operation and positioning is by design sluggish.

Improved Method – Motor control performance can be greatly improved by employing some means of true position feedback. By accurately tracking position, the user is no longer forced to be as conservative with respect to the acceleration or speed used in operating the motor. In addition to using the position feedback signal to determine the actual position, a position error term (target position less observed position) can easily be calculated, monitored and used to alter the amount of current delivered to the motor so as to overcome variations in external inertia and friction. This is what is referred to as closed-loop motor control, and it enables the motor to be driven to its full torque-speed potential. Since the knowledge of position can only be as accurate and timely as is the means by which the true position is obtained, it is important to use a feedback sensor with a high enough resolution and accuracy. It is also imperative to synchronize the reading of position with the commanded position, lest the position error term cannot be accurately calculated. It is because of the challenges associated with the achievable resolution and synchronization that Nor-Cal Products' Intellisys™ line of valves and controllers employ the back EMF generated by the motor itself as a means of determining its position.

EFFECTS ON PRESSURE CONTROL

The enhancements in the motor and valve drive technology as have been discussed up to this point would have little importance if they could not be tied to quantifiable improvements in pressure control. A live test was designed and conducted in order to illustrate and quantify any possible benefits of using higher speed and higher position resolution valve drive technology, such as in the case with a direct drive butterfly valve using back EMF position sensing. A multi-step wafer recipe was executed in a 35 liter chamber outfitted with throttling valve in the downstream position.

The Benefits of Speed – As can be seen in Figure 1 the first notable event occurs in the pressure transition step in which the pressure set-point is suddenly increased. As each of the three controllers drives their respective valves completely closed, the chamber pressure rises accordingly. The Intellisys™ valve closes completely in 0.125 seconds, as compared to 1.7 and 2.0 seconds of System 1 and 2, respectively. The result is an immediate onset of pressure rise allowing the set point to be reached that much faster.

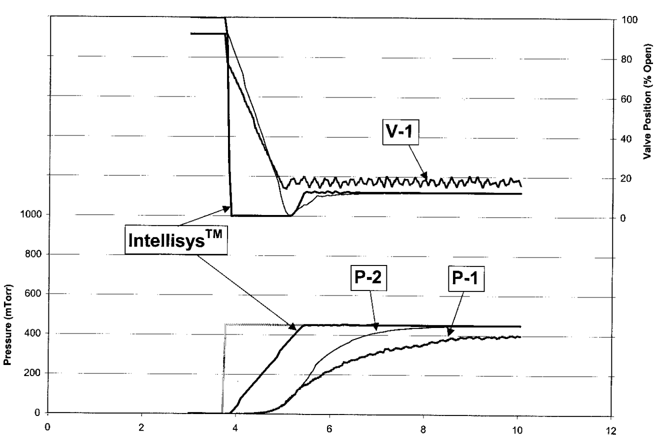

Figure 1: Pressure Transition Using100 mm Butterfly Valves

Further contributing to the slower time to set point is System 2's gradual ramp toward set-point. The valve's relatively low speed necessitates a slow approach to set-point, lest significant pressure over-shooting would occur.

The Benefits of Resolution – Ultrafine step resolution, such as that which can be achieved through back EMF position sensing, can play a very important role in the ability to control pressure at all. This benefit is especially noticeable in large valves that are also sealing valves – such as throttling gate and pendulum valves.

Figure 2 shows a comparison between two ISO-200 sealing throttling pendulum valves. In this diagram, System 1 has been fitted with a stepper motor drive using back EMF as the position sensing mechanism. System 2 uses standard open-loop type motor control. As is illustrated by the chart, almost indistinguishable moves by the Intellisys™ valve plate result in smooth pressure control at 1000 mTorr. In contrast, a significant amount of "hunting" is evidenced by the System 2 valve, which in this case translates in to 50 to 60 mTorr pressure swings. When occurring in critical processes or at sensitive times within a process, pressure swings such as these can have a dramatic and detrimental effect on the uniformity and yield of the wafer.

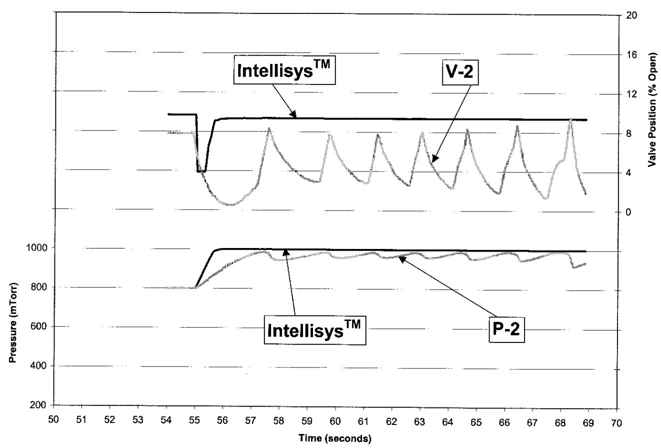

Figure 2: Pressure Control Stability Using 200 mm Pendulum Valve

CONCLUSION

In summary, it has been shown how open-loop motor control differs from closed-loop motor control, and specifically how back EMF can be used to provide an unparalleled method for motor position feedback. Because of the high precision and resolution of such feedback mechanisms, ordinary stepper motors can be employed in ways not possible by conventional means. The advancements in motor control capabilities were then substantiated by demonstrating how cluster tool throughput and wafer yield can positively be impacted by the resultant improvements in pressure control.