Waters Corporation Variable Aperture Slit System

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Abstract

The goal of this project was to design a Variable Aperture Slit (VAS) system used for providing different resolutions of light to be projected into a photodiode array (PDA) for examining the composition of a fluid sample. The VAS will consist of different slit sizes that will be used to limit or refine the light from an ultraviolet (UV) or deuterium light source. The VAS will attach to a holder aligned between a reflected and refracting mirror to permit a certain amount of light with a specific resolution that is unique to each slit size through from the light source to the PDA. Prior to passing through the slit, the UV light will pass through a sample fluid, prepared via liquid chromatography separating the components of a substance, which will absorb various wavelengths of light corresponding to the absorption pattern of the substance. Based on the remaining wavelengths of the light which are passed through the slit and then refracted into an optical detector, the composition of the sample fluid can be determined. In the detector, each slit width will provide a different signal-to-noise ratio and resolution.

Based on the need for a VAS system, an accurate and repeatable design is required to ensure the quality of the system. A simple design focused on movable holders for interchangeable slits provides repeatability for the process and manufacturing. Current designs display the benefits of a movable holder system. Physical models will be created based on the final design and tested to verify the system maintains accurate and repeatable with a rotating motor. The device will be able to be calibrated based on repeatable testing results for use in implementation for full scale manufacturing.

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Use of a Variable Aperture Slit System

An optical detector measures the intensity and angle of remaining wavelengths of light that have passed through a sample. The width of a slit on an aperture directly correlates to the intensity and signal-to-noise ratio of a given wavelength. The closer the size of a particular wavelength is to the size of the slit, the more intense and accurate the detection of a particular component can be. Each additional aperture slit a sample is compared to increases the accuracy of the identification of a sample.

Waters Corporation Sponsor and Design Constraints

Design Objectives

A prototype capable of transitioning between a minimum of two slits was desired. The system was expected to be repeatable, fit into the casting shell of the current product with minimal modifications, and not impede on the light pathway. The final beam of light diffracted into a PDA detector must match its corresponding diode within 25µm to ensure less than a 30% drop in overall intensity of the examined wavelength.

Design Requirements

A beam of light traveling through the VAS system must maintain a straightness of travel within 10µm upon exiting the prototype and before entering the PDA detector. For all iterations of rotation, the system must return to the same position within 1µm of its original position. The design of the system must fit into a cavity that is approximately 2.4” tall and can have a slit holder no larger than a total diameter of 0.6” for 1” of the total clearance, with a wider clearance parts from the bottom of the casting to 1.187” below.
Analyzed Design Concepts

From four original designs, two designs fulfilled the design constraints. The system providing the greatest quantity of slits to switch between was selected for use.

Four designs were investigated, analyzing vertical actuation of a set of slits, rotating a panel with multiple integrated slits, motion of parallel plates to adjust slit size, and rotation of a holder that held multiple slits. Each system was compared based on its ability to fulfill design criteria and ranked based on its ability to reach accuracies and design requirements.

The rotational panel system, represented similar to a windmill (Rep. 5.1), permitted up to 8 precision etched slits to be placed on a panel. Rotating the panel would require removing large quantities of material from the product casting, and any rotation errors would have created slit widths larger than those intended or desired.

The parallel plate system (Rep. 5.3) permitted near unlimited slits from being used. For this system the accuracies required to maintain the parallelism in the plates to ensure a consistent slit width as well as needing to machine out an entire casting wall prevented the design from being feasible.

The vertical actuation system (Rep. 5.2) was a feasible design option, actuated by a linear motor. Based on height constraints in the casting, the number of slits was limited to only two sizes for the system due to motor heights. The system was proven feasible but finding a system greater than the minimum number of slits was desired.

The rotational holder system (Rep. 5.4) rotated between a set number of fixed slits. The slits would be identical to the current fixed configuration, making them interchangeable for various sizes depending on customer needs. Based on calculations, the minimum angle between each slit panel without causing light interference was 55º allowing for a maximum of three slits, which gives one additional slit size from the vertical actuation system. The initial rotational holder system’s thin walls of 0.5mm were too thin to be machined or drilled, making them susceptible to fatigue and incapable of being machined properly.

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**Recommended Design Concept**

The final design incorporates a rotational system, containing three slits angled to prevent light interference able to be rotated accurately between each position. The system can be customized for individual customers and geared to be rotated to different angles if different sized design is required.

**Design Description**

The final design was based off the concepts for the rotational holder system above (Rep. 5.4) but modified so that there is sufficient material to structurally hold the slits and the shape by having a solid holder with light channels (black anodized to prevent reflection) through the holder (Rep. 7). The rotational system optimizes the 0.6” cavity available space by holding three slits across the width of the system on a holder with a diameter of 0.252” sitting on a structural base that is 0.5” in diameter used for the rotation of the system. The holder then sits on a stepper motor and gearbox configuration with a ratio of 27 to 1 (with an actual value of 26.85 to 1 with tested backlash) making the entire system approximately 2” in height.

**Analytical Investigations**

To determine the optimal number of slits that would not cause interference with the light path a mathematical analysis and SolidWorks model were used. The model and analysis gave 55º as the optimal angle. An angle of 60º was selected based on stepper motor and gearing limitations from supplying companies, and to reduce cost. The gear ratio was selected to limit the value to increments of a 0.067º for each step. Adjusting for the gear ratio a precise 60º motion can be obtained by moving 895 steps with expected backlashes. With a 0.067º rotation any unexpected backlash or missteps should minimally affect the accuracy of the system.

**Experimental Investigations**

Using a fixed single slit, base tests were performed to analyze the effect off centered slits would have on the system. The experiment displayed a 30% drop in intensity for the system, as well as smaller images of the slit, detailing the decrease in size.

**Key Advantages of Recommended Concept**

The rotational system has a customizable configuration of interchangeable slits for each customer to have three different slit widths, each able to be closer to the wavelength of the typical substances a customer examines. The design could also incorporate an additional vertical actuation component to add an additional three slits. The system can also be made more accurate with a more refined rotational control system.
Financial Issues

Prototyping for Waters Corporation was approximately $400 in total cost for all control systems, motor systems, and machined components. Converting the prototype to a mass production setting will allow for costs to drop by a minimum of $100 based on increased order quantities. An initial cost to move the prototype system to mass production is expected based on changes to the current aluminum casting mold. Until the mold can be completed a precise boring operation will be necessary.

Recommended Improvements and Second Phase

Based on final results a next phase of the design permits the opportunity to tighten the tolerances of the rotational system, permitting less than a 30% drop in intensity. A second phase of the project can integrate a vertical actuation system in tandem with the rotational design to allow for six different slit widths giving the system more versatility.