SHUTTER SUBSYSTEMS for INFRARED IMAGERS CVI MELLES GRIOT

WHITE PAPER

Requirements for shutters used in Infrared Thermal Weapon Sight (TWS) systems, Driver Vision Enhancement (DVE) and other thermal imaging systems are becoming increasingly more demanding. These performance requirements have been achieved using a unique, modular, reconfigurable rotary drive actuator with bi-stability and direct connection to the blade. A "Smart Shutter" acts as a complete sub-system that can be tested as an integral module. A multi-blade variant has been developed that retains the reliability of the rotary drive system and decreases the physical size of larger-aperture shutters. Predictions of next-generation application-specific shutter designs will be offered in the paper.

1. SWIR, LWIR SHUTTER REQUIREMENTS

Requirements for shutters used in Infrared Thermal Weapon Sight (TWS) systems, Driver Vision Enhancement (DVE) and other thermal imaging systems are becoming increasingly more demanding. Low cost, uncooled night vision systems were initially developed for military systems, particularly for weapons and transportation applications. Stringent design requirements were created for high reliability, shock resistance, low power, small size and light weight. The service condition of operation was between -40° and 65° C. In portable applications, the imager had to be light and power efficient to reduce battery weight. In life-critical applications, subsystems were required to be highly reliable and have long life.

The market is evolving into non-military applications. The size of the imaging pixels is decreasing from 25 to 17 microns (12 micron pitch on the drawing boards) as the number of pixels per sensor is increasing from 240 by 360 to 480 by 640 and even higher formats. These two opposing design construction characteristics help maintain a fairly constant imager package size [2]. Camera size is decreasing for lower resolution sensors, requiring smaller and even lower powered system solutions. Smaller camera size and reduced weight continue to be important considerations for man-portable applications. Increasing volume of sensor production is reducing camera cost and opening large volume commercial applications that require lower cost shutters to match the lower prices of the imagers.

The optimal shutter for thermal imagers should block radiation during non-operation, and remain open during possibly long imaging events. The blade must briefly and intermittently block the sensor to recalibrate the sensor during operation. Bistable shutters are preferred in these applications because they draw minimum power and generate minimum heat. During calibration, the blade and housing must present surfaces to the imaging array having a known, uniform temperature and emissivity. Blade motion should be rapid to reduce non-imaging time during calibration.

2. UNIQUE MODULAR CONFIGURABLE ROTARY ACTUATOR

These performance requirements have been achieved using a unique, modular, reconfigurable rotary drive actuator with bi-stability and direct connection to the blade. The author's previous paper [1] outlined the structure and advantages of such an actuator. New application methods and enhancements have been developed for such actuators that expand application space, ease of use and reliability.

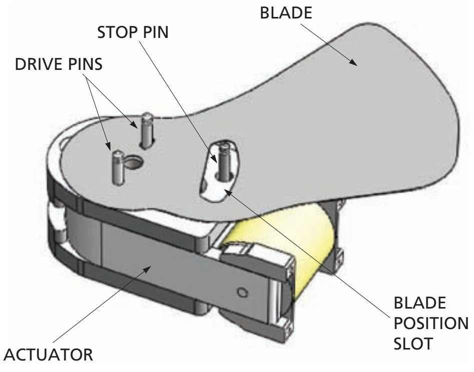

Figure 1. Rotary Drive Actuator.

The rotary drive actuator has a bistable rotor that transfers power to the blade through two hardened drive pins. A hole and a slot in the blade engage the drive pins. The direct engagement of the drive pins reduces wear as compared to earlier systems that used an intermediate member or drive ring or linkage to move the shutter blade. The rotary drive shutter includes a shock-mounted stop pin that engages a slot in the blade to provide two accurately defined stop positions. Precision forming processes such as EDM and photochemical etching accurately define the blade slots and therefore the blade positions.

The blade is made of spring steel with a proprietary polymeric coating and has a high and constant emissivity from 2 to 17 microns. Spring steel blades wear better and are lighter weight than thicker aluminum blades. The durable polymeric coating offers very low sliding friction and eliminates the generation of particulates. The combination of hardened drive pins, steel blade and coating create a rotary drive shutter that has life expectancies of over two million cycles with low wear and debris.

The actuator is supported by a frame that defines an optical aperture that is part of the optical system. The frame has detail that accurately aligns the aperture and blade to the lenses, sensor and housing of the imager. Shutter frames have been made of aluminum, magnesium and polymers. Polymeric and magnesium frames offer low cost and light shutters respectively. The elements of the shutter can be rapidly configured to custom fit applications. CVI Melles Griot currently has tens of thousands of shutters operating in over a dozen configurations.

The rotary drive shutter continues to evolve to meet emerging design needs. The original actuators were designed for nine volt drive. Emerging applications prefer a drive voltage more compatible with portable electronics. A new actuator has been designed to operate at three volts, which is more compatible with battery and electronic drive voltages. Elastomeric stops have been developed to reduce the sound of the blade impact against stops. The elastomeric pads are designed to operate over the wide operating temperature range and have long life.

3. SMART SHUTTERS

CVI Melles Griot defines a "Smart Shutter" as a shutter having on-board electronic drive and sensors. A schematic of the smart RDS 2.2 shutter is shown in Fig. 2. This shutter is two bladed with a 35 millimeter clear aperture and on-board circuit board. The circuit board carries sensors to verify blade positions for applications requiring enhanced safety levels. The rotors contain a powerful magnet that securely locks the blade in either the open or closed position in the absence of power. The magnetic field passing through the stator changes depending on the rotor's position. Hall Effect sensors located adjacent to the stators of the actuators detect the magnetic flux of from the rotor to determine blade position. The non-optical sensors eliminate optical radiation in the system that would be present with an optical sensor, and eliminates the wear problems of mechanical switches.

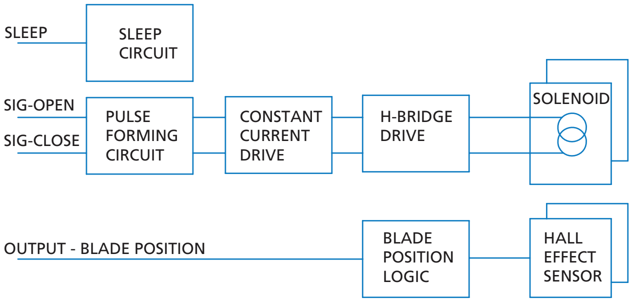

Figure 2. RDS 2.2 Circuit.

The shutter uses bidirectional electrical pulses to reverse the state of the shutter blade. The duration and power of the pulses affect blade transition time, life and noise characteristics. Over the wide operating temperature range of these shutters, the resistance of the drive coil can change significantly from +17 percent at 65° C to –24 percent at -40° C. If driven at a constant voltage, the change in coil resistance causes the shutters to be overdriven at cold temperatures and under driven at high temperatures. A constant current drive on the RDS 2.2 board provides constant drive power throughout the broad temperature range and during life to minimize noise and wear at low temperatures and ensuring reliable operation at high temperatures throughout the shutters life. The size of the actuators is reduced by driving them at high power that cannot be sustained continuously. Circuitry located in the on-board electronics limits power delivery to optimized pulses and prevents continuous drive.

The schematic for the RDS-1, generation 2 shutter is shown in Fig. 3. Simpler circuitry is used in this small, single blade shutter. Sufficient space exists within the shutter to include a Hall-effect sensor to determine blade position, as well as an H-Bridge driver. The two components share a common 5 volt power supply to reduce wire count. The circuitry is designed to accept 3 to 5 volt input/output logic separate from a five volt drive. The on-board circuitry permits these shutters to be wired directly to a camera controller and battery system.

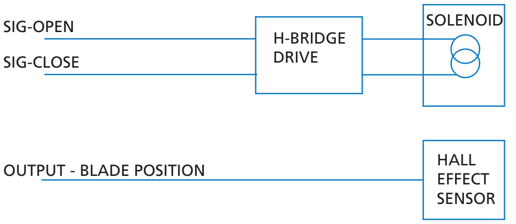

Figure 3. RDS 1.2 Circuit.

Calibration of the imager requires the system to know the temperature and emissivity of the shutter blade and adjacent housing. Temperature sensing devices can be incorporated onto the circuit boards in smart shutters. A temperature sensor on the circuit board can determine the temperature at the shutter blades. These sensors are typically either a thermistor or a semiconductor temperature sensor. All these circuits can be easily configured to permit fast, rapid development of camera systems, even with low production volumes.

4. MULTI BLADE CONFIGURATIONS FOR COMPACTNESS

A multi-blade variant has been developed that retains the reliability of the rotary drive system and decreases the exterior diameter of larger-aperture shutters. Previous rotary drive shutters had ratios of the outer diameter to the clear aperture of more than two. In many emerging applications, the outer diameter is required to be less than twice the clear aperture.

The new shutter design uses two or more small blades with each actuator. Figures 4 and 5 shows the design of a two drive unit, four-bladed RDS-4 shutter. Two blades on each actuator share a common pivot and use only one of the two actuator drive pins to rotate the shutter blades. The leading blade travels the full distance from open-aperture to cover a central quadrant of the clear aperture. A stop pin operates on a slot in the full-travel blade to define the open and closed positions. The second blade on the actuator uses the same pivot and stop pin, and engages the actuator drive pin with a drive slot instead of a drive hole. The drive slot causes the second blade to travel a shorter distance than the first blade to cover a second quadrant not covered by the first blade. The two blades secure half the clear aperture. The set of blades driven by the second actuator covers the other two quadrants to completely close the shutter.

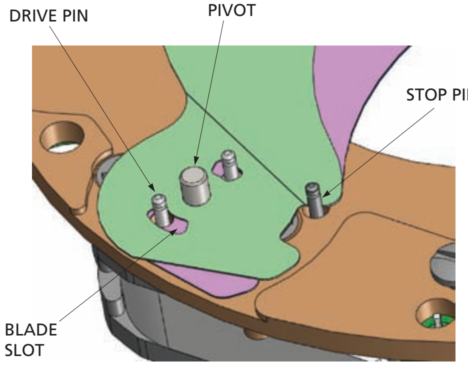

Figure 4. Multi-blade rotary drive, partial view.

The pivot location, blade locating detail and drive detail in this design must be accurately controlled. Precision etching of each of the four blades accurately locates the blades in the open and close position. Two or even three blades can be used with a single actuator to create a shutter with an extremely small outer diameter relative to the large clear aperture size.

The RDS-4 shutter has a 34.8 millimeter clear aperture and an outer diameter of 64 millimeters, a ratio of 1.84. The shutter components were developed to maximize life. The RDS-4 shutter is expected to operate reliably for over one million open-close cycles.

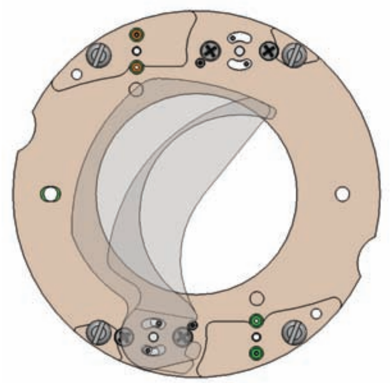

Figure 5. RDS-4, multi-blade rotary drive, partial view.

The previously described miniature rotary drive shutters can move blades for clear apertures of up to 35 millimeters in diameter. To date, shutters with clear apertures greater than 35mm needed a single large solenoid to drive 5 or more blades through a drive ring that levered the shutter blades into an open or closed position. Power from the solenoid was distributed through the rotating blade ring to each levered shutter. Such shutters have many wear points in the ring, pivots and drive slots that limit their reliability and life.

A new multi-blade rotary drive shutter has been developed that has a 58 millimeter clear aperture and a rotary drive actuator on each of five blades, Fig. 6. The design has each of five blades connected directly to a rotary drive actuator. A synchronizing ring contains slots that engage one of the drive pins on each actuator to ensure that the blades move smoothly and in a synchronized manner between the open and close positions. Because the ring does not carry driving power, and the shutter life is over 2 million cycles. The synchronization ring lets the blades counterbalance each other making the blade positions highly stable against shock and vibration.

The RDS-5 shutter is 10.49 millimeters thick, thinner than comparable shutters that use a single large solenoid. Reliability is further improved because of a redundancy of drivers. Excess heat in the imaging area has the potential to degrade image quality. Because the shutter is only driven by pulsed electrical signals when opening or closing the blades, and is power-free when in the open and close positions, less I^2R power is dissipated near the imager.

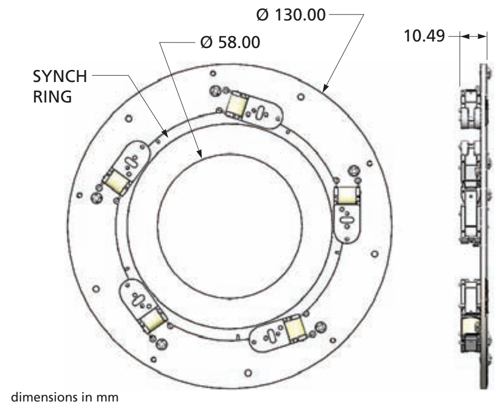

Figure 6. Rotary Drive applied to large aperture shutters.

5. SHUTTER DEVELOPMENT FORECAST

Smart shutters can increase in electronic complexity. Figure 7 is a schematic of a concept of a smart shutter using a low-cost, small microprocessor. The microprocessor eliminates logic circuitry and enhances shutter capabilities. The microprocessor uses serial communication to receive drive commands and communicate data. The shutter microprocessor senses current and can pulse width modulate an H-Bridge to provide a constant current to the solenoid over wide temperature conditions. Back EMF can be measured to determine blade position and provide variable power to the solenoid during blade motion to minimize blade impact. Reduced blade impact increases shutter life and reduces audible sound from the shutter.

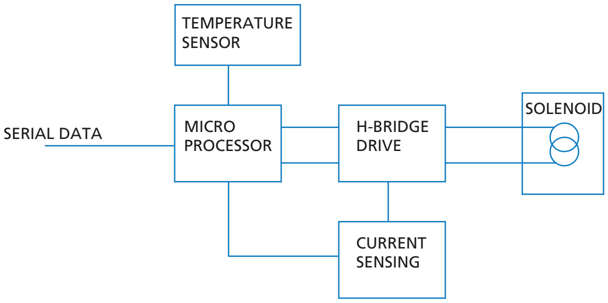

Figure 7. Advanced Smart Shutter.

The rotary drive shutter system has proven to be adaptable to evolving market needs, including usage in systems requiring electronic sensors and drives, shutters requiring small OD to CA ratios, and large aperture shutters. Infrared imaging systems are increasing in resolution and decreasing in size and cost. Military applications continue to drive demand for lighter, smaller, quieter, and more power efficient shutters. Commercial applications require lower cost. These applications continue to operate in wide temperature ranges with high shock and vibration.

High performance rotary drive shutters will continue to evolve to meet needs of the night vision market. Shutters will continue to become smarter to improve operating characteristics. As the market grows for night vision systems, smaller envelope shutters will be developed to match smaller sensors and optics while maintaining the high-performance characteristics of rotary drive shutters. New rotary drive systems will be developed to reduce costs of shutter systems for emerging lower-cost, higher volume transportation imagers.

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