## Miniature, Variable-Speed Control Moment Gyroscope

*Goddard Space Flight Center, Greenbelt, Maryland*

The Miniature Variable-Speed Control Moment Gyroscope (MVS-CMG) was designed for small satellites (mass from less than 1 kg up to 500 kg). Currently available CMGs are too large and heavy, and available miniature CMGs do not provide sufficient control authority for use on practical satellites. This primarily results from the need to greatly increase the speed of rotation of the flywheel in order to reduce the flywheel size and mass. This goal was achieved by making use of a proprietary, space-qualified, high-speed (100,000 rpm) motor technology to spin the flywheel at a speed ten times faster than other known miniature CMGs under development.

NASA is supporting innovations in propulsion, power, and guidance and navigation systems for low-cost small spacecraft. One of the key enabling technologies is attitude control mechanisms. CMGs are particularly attractive for spacecraft attitude control since they can achieve higher torques with lower mass and power than reaction wheels, and they provide continuous torque capability that enables precision pointing (in contrast to on-off thruster control).

The aim of this work was to develop a miniature, variable-speed CMG that is sized for use on small satellites. To achieve improved agility, these space-craft must be able to slew at high rate, which requires attitude control actuators that can apply torques on the order of 5 N·m. The MVS-CMG is specifically designed to achieve a high-torque output with a minimum flywheel and system mass. The flywheel can be run over a wide range of speeds, which is important to help reduce/eliminate potential gimbal lock, and can be used to optimize the operational envelope of the CMG.

*This work was done by Steve Bilski, Robert Kline-Schoder, and Paul Sorensen of Creare Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15887-1*

## NBL Pistol Grip Tool for Underwater Training of Astronauts

*Goddard Space Flight Center, Greenbelt, Maryland*

A document discusses a lightweight, functional mockup of the Pistol Grip Tool for use during underwater astronaut training. Previous training tools have caused shoulder injuries. This new version is more than 50 percent lighter [in water, weight is 2.4 lb (≈1.1 kg)], and can operate for a six-hour training session after 30 minutes of prep for submersion.

Innovations in the design include the use of lightweight materials (aluminum and Delrin®), creating a thinner housing, and the optimization of internal space with the removal of as much excess material as possible. This reduces tool weight and maximizes buoyancy. Another innovation for this tool is the application of a vacuum that seats the O-rings in place and has shown to be reliable in allowing underwater usage for up to six hours.

*This work was done by Michael Liszka, Matthew Ashmore, Mark Behnke, Walter Smith, and Tod Waterman of ATK Spacecraft, Systems and Services for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16060-1*

## HEXPANDO Expanding Head for Fastener-Retention Hexagonal Wrench

*Goddard Space Flight Center, Greenbelt, Maryland*

The HEXPANDO is an expanding-head hexagonal wrench designed to retain fasteners and keep them from being dislodged from the tool. The tool is intended to remove or install socket-head cap screws (SHCSs) in remote, hard-to-reach locations or in circumstances when a dropped fastener could cause damage to delicate or sensitive hardware. It is not intended for application of torque.

This tool is made of two assembled portions. The first portion of the tool comprises tubing, or a hollow shaft, at a length that gives the user adequate reach to the intended location. At one end of the tubing is the expanding hexagonal headfitting with six radial slits cut into it (one at each of the points of the hexagonal shape), and a small hole drilled axially through the center and the end opposite the hex is internally and externally threaded. This fitting is threaded into the shaft (via external threads) and staked or bonded so that it will not loosen. At the other end of the tubing is a knurled collar with a through hole into which the tubing is threaded. This knob is secured in place by a stop nut.

The second assembled portion of the tool comprises a length of all thread or solid rod that is slightly longer than the

steel tubing. One end has a slightly larger knurled collar affixed while the other end is tapered/pointed and threaded. When the two portions are assembled, the all thread/rod portion feeds through the tubing and is threaded into the expanding hex head fitting. The tapered point allows it to be driven into the through hole of the hex fitting. While holding the smaller collar on the shaft, the user turns the larger collar, and as the threads feed into the fitting, the hex head expands and grips the SHCS, thus providing a safe way to install and remove fasteners. The clamping force retaining the SHCS varies depending on how far the tapered end is inserted into the tool head.

Initial tests of the prototype tool, designed for a 5 mm or # 10SHCS have resulted in up to 8 lb (≈35.6 N) of pull force to dislodge the SHCS from the tool. The tool is designed with a lead-in angle from the diameter of the tubing to a diameter the same as the fastener head, to prevent the fastener head from catching on any obstructions encountered that could dislodge the fastener during retrieval.

*This work was done by John Bishop of QinetiQ for Goddard Space Flight Center. Further information is contained in a TSP (see page 1).*
GSC-16109-1

# Diagonal-Axes Stage for Pointing an Optical Communications Transceiver

**Potential applications include steering aircraft-mounted cameras for ground imaging.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Traditional azimuth-elevation ("az-el") stages are used to point a variety of devices ranging from large optical telescopes to tank guns. Such a stage typically has an "elevation" stage having a horizontal axis mounted on an "azimuth" stage with a vertical axis. Both stages are often motorized.

Optical communications transceivers often require two-axis motorized control, as when the communications link is between a ground station and an aircraft or satellite. In such applications, the traditional azimuth-elevation stage has two important drawbacks: a "gimbal lock" exclusion zone at zenith and susceptibility to pointing errors caused by backlash. Az-el stages in which the azimuth stage cannot rotate a full 360° have the additional drawback of an azimuth exclusion zone.

The diagonal-axes stage described here mitigates or eliminates all of these problems. Instead of one vertical axis and one horizontal axis, a diagonal-axes stage has two horizontal axes, both oriented at 45° to the trajectory of the target. For example, a ground station located on the equator tracking a satellite with an equatorial orbit would have one axis parallel to northeast and southwest, and the other axis parallel to northwest and southeast.

The diagonal-axes stage is considerably less vulnerable to backlash. If it is correctly oriented, its axes rotate in only one direction during an overhead pass by a satellite. As a result, the effects of backlash may be inherently eliminated. If the gravity-induced torque on either axis changes during the pass, then backlash may become important during the part of the pass where the gravity torque, instead of opposing the motion of the stage, pushes the stage in the direction of motion. This can result in the loss of gear-to-gear contact in one or more stages of the gear reduction mechanism. In this case, a preload spring used to eliminate backlash need only be sufficiently strong to overcome the gravity torque, i.e. it need not overcome friction in the gear train.

The diagonal-axes stage is not backlash-free for arbitrary target trajectories such as an aircraft might execute. If properly oriented for any particular satellite, however, it is backlash-free for all passes of that satellite, which will trace out parallel paths on the sky, and for all passes of any other satellite that are perpendicular to the first. It will also be backlash-free for some fraction of other satellite trajectories.

*This work was done by Martin W. Regehr and Vachik Garkanian of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).* NPO-47427
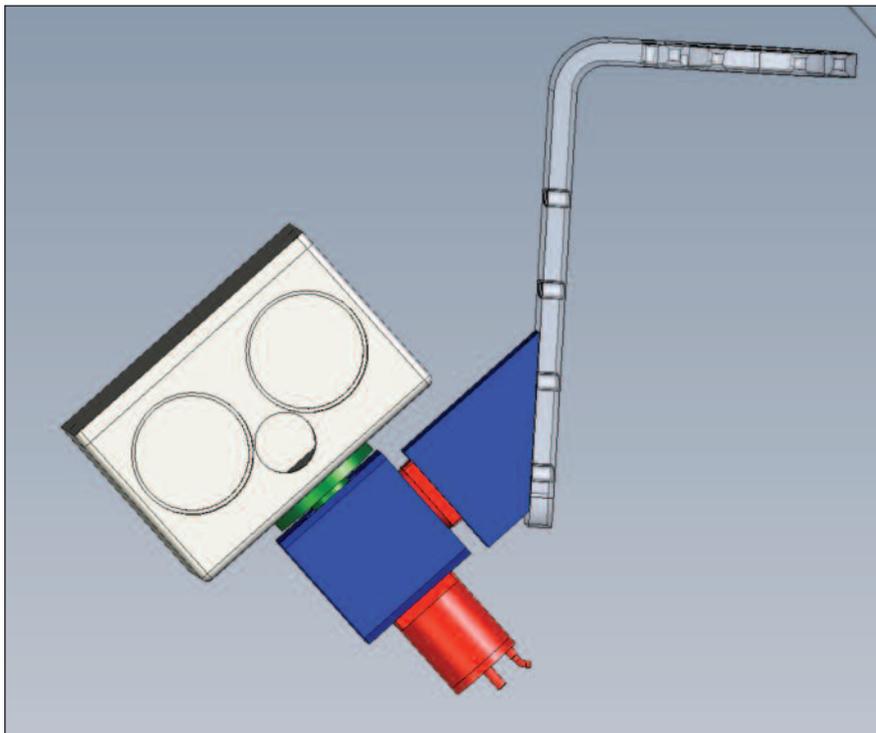


A design based on the **Diagonal-Axes Stage** principle. Motors are shown in red, wedge and intermotor block are shown in blue, and the payload hub is green. The box at left with three circular apertures is an example of an optical payload; the L-bracket at left is a mounting bracket supporting the stage. Direction of travel is right-to-left.