National Aeronautics and Space Administration

NASA**facts**

Space Technology
Game Changing Development
Bulk Metallic Glass Gears

NASA is developing technologies that will allow exploration of promising places in the solar system ranging from Mars to the icy moon of Jupiter, Europa. These locations have extreme environments that require hardware to withstand temperatures below –150 °C. To put that in perspective, the lowest recorded temperature on any location on Earth's surface was –93.2 °C (–135.8 °F) on an Antarctic plateau.

More science can be accomplished on icy body missions, like those to Europa, if spacecraft mechanisms can operate without power consuming heaters. Researchers are developing unheated gearboxes to operate in these environments using custom bulk metallic glass (BMG) alloys invented at NASA specifically for this application. Gearboxes developed with the BMG technology must be capable of operating at surface temperatures of –173 °C (–280 °F).

The composition and amorphous atomic structure of these new BMG alloys make them tougher than ceramics and twice as strong as steel, with better elastic properties than either. Combined with greater wear and corrosion resistance, these alloys are promising gearbox component materials. A gearbox is a mechanical system that uses gears and gear trains to provide speed and torque from a rotating power source to another device, like a car's transmission adapts engine output to drive the wheels.

Steel **Amorphous metal**

Amorphous metal can be cast into the final shape with no post-casting finishing steps required. Precise teeth shapes can be incorporated into the mold and replicated near-perfectly into the castings. Certain alloys of amorphous metal (metallic glass) also have extremely good elastic, contact stress, and galling properties for this application.

The BMG Gears project within NASA's Space Technology's Game Changing Development Program (GCD) plans to demonstrate capabilities of custom BMG alloys in heaterless planetary and strain-wave gearbox configurations. Enabled by the materials working in extreme cold environments, mechanisms such as these could increase science return by reducing power consumption, mass, system complexity, and operational constraints. Applied to a Mars Curiosity type rover, for example, this technology would enable nighttime operations during winter while saving 950 watt-hours per day; enough to run the remote sensing mast while moving. The ~7 kg in ancillary electronics mass savings could allow another instrument to fly.

Currently there are no materials specifications available that define acceptable ranges for the constituent components and minor elements in the BMGs that enable these gearboxes. NASA is working closely with industry to develop those specifications and mature a supply chain for the BMG alloys. An important benefit of using BMG alloys is that components can be directly molded from the material and the supply chain for gearbox components in this manner is being similarly matured.

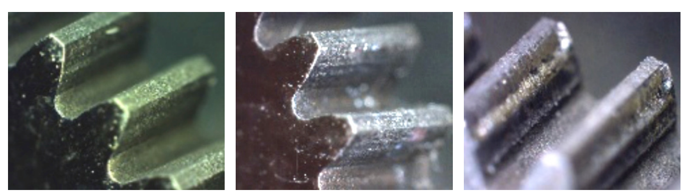
Researchers want to determine operational boundaries and mechanism lifetime because the ability of BMGs to perform at icy body temperatures around –173 °C has not yet been proven. Also, a heaterless planetary gearbox operating around –173 °C has never before been produced so there is a possibility that bearings, or other ancillary components not made from BMGs, may not have the necessary performance capability.

Some encouraging insights are being revealed early on. NASA developed a copper- and zirconium-based BMG alloy that was tested in a dry lubricated hybrid gearbox. Using a steel drive gear and BMG planet gears, this gearbox configuration ran 75 percent longer than a dry lubricated all-steel gearbox (14 million revolutions versus 8 million revolutions). Furthermore, gear-on-gear testing has been performed using a drive gear and a brake gear to establish a contact stress between two geometrically similar, unlubricated gears of the same material composition. The test results indicate even greater potential for dry lubricated all-BMG gearboxes.

The BMG Gears project seeks to advance the technology for project infusion or a technology demonstration by maturing a cryo-capable BMG-based planetary gearbox with demonstrated performance exceeding current products. To do so, an understanding of the engineering challenges is necessary along with establishing design rules and guidelines for BMG alloy use in cryo-gearboxes. These technological advances mean a potential Europa Lander mission could include actuators or mechanisms without allocating power to heating gearboxes, thereby increasing the science return through increased mission lifetime or additional instrumentation.

The GCD Program investigates ideas and approaches that could solve significant technological problems and revolutionize future space endeavors. GCD projects develop technologies through component and subsystem testing on Earth to prepare them for future use in space. GCD is part of NASA's Space Technology Mission Directorate.

For more information about GCD, please visit
http://gameon.nasa.gov/



Nominal BMG gear | **BMG gear after 3 hr wear** | **Steel gear after 3 hr wear**

More than 3 million cycles were achieved at less than –100 °C with dry lubricated hybrid gearbox.

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