the **difference** between

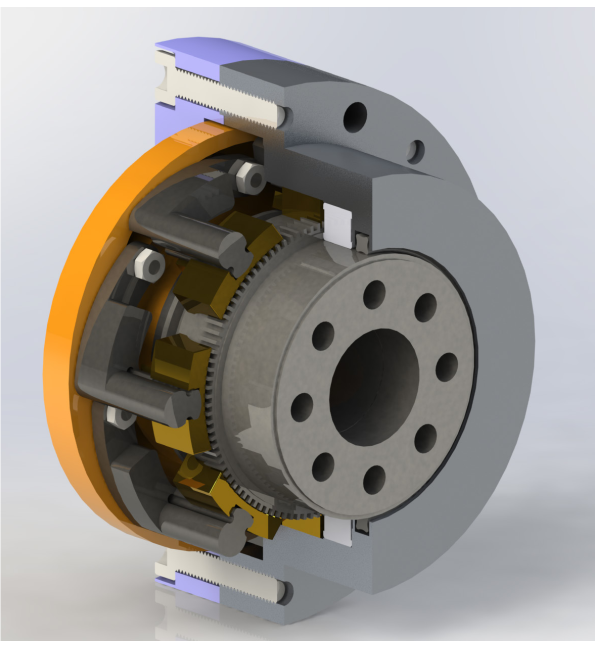
THE DIFFERENCE BETWEEN:

Strain Wave Gearing and MOTUS M-DRIVE Gearing

Through innovations in design, drive technology has taken a leap forward from mechanisms used since the 1950s. At the same time, design upgrades have allowed for smaller footprint, lighter weight, and higher torque densities.

TODAY'S AUTOMATION APPLICATION DESIGNS

Automation designers need specific requirements for a geared solution option to fit various new applications including medical, agriculture, defense, and the growing autonomous vehicles market, as well as brand-new applications coming to market. New inventions across multiple automation markets in robotics and motion control are requiring or opting for geared solutions to be lighter weight, smaller footprint, run faster, and higher torque density. In addition, designers are looking for solutions that provide an overall reduction in solution costs, which may include a variety of material compositions. Designers of new innovations are wanting to use various cutting edge technology solutions to differentiate their product in the marketplace.



Section View, CAM, Rocker Arms, Pads

A common challenge faced by robotic equipment suppliers and motion control applications is the high cost and limited performance of the standard strain wave gear drives they have been using for years. For example, service robots that perform useful tasks outside the area of industrial automation such as agriculture, medical, logistics, construction, and inspection are often costly and limited in performance due to the older technology used. The fast-growing, collaborative robot industry is looking to build lighter weight, higher performance, and smaller footprint robots that work autonomously or alongside humans. Other traditional, large, industrial articulated robots that are much more expensive to build can also benefit from this latest technological trend.

STRAIN WAVE SUCCESS AND LIMITATIONS

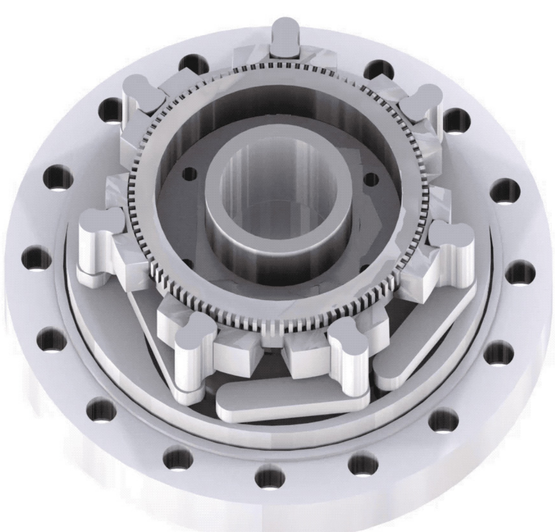
Advancements in strain wave gearing design ([Click here for basic design information]) are often limited to new players offering a less expensive or slightly varied design resulting from the expiration of the original patent. This technology can have various limitations, including low efficiency due to friction and heat generated from gear contact, limits in speed due to the elasticity of the flexible spline, and difficulty to get a repeatable controlled rate of motion. The potential for these limitations means that reliability can be a concern and can lead to the need for early replacement of the drive.

NEW APPROACH TO GEAR ARCHITECTURE

In the drive toward improving standard strain wave designs, Carlos Hoefken, CTO and Founder of Motus Labs, brought his knowledge as a robot systems integrator to the current strain wave drive concept. Frustrated with the high cost and limited specifications of current gear-drive technology, Carlos was determined to develop a smarter solution and worked with the Motus Labs team that studied the functionality of human and non-human body movement to come up with their innovative gear design. The result is his unique, breakthrough precision transmission architecture that currently holds nine U.S. patents issued and additional U.S. and international patents pending.

M-DRIVE design has replaced the age-old brute-force gear teeth of standard strain wave drives (see Sidebar I: Inside M-DRIVE Technology). Utilizing a CAM driven design, along with custom software tools, Motus Labs can precisely control multiple gear pads to not only provide outstanding torque density but also to eliminate backlash and minimize lost motion. This technology allows the use of a variety of materials, depending on specific needs for weight, cost, or material-specific applications. M-DRIVE technology enables high torque densities in a compact, lightweight package. (*Click here:* https://motus-labs.com/how-it-works/ for a 360-degree animation.)

Unlike strain wave drives, the M-DRIVE does not rely on the rolling engagement of involute gearing; rather, the CAM-drive gear blocks provide up to 80% engagement of the output ring surface area, which distributes load stresses over a much larger surface area. An increase in load distribution enables an increase in torque density for a given unit size. (*Click here to read the white paper:* "Motus Labs M-DRIVE Brings Value to the Robotics Industry")



An example of M-DRIVE technology.

The angular transmission error of strain wave drives typically varies periodically, with the primary component at twice per input revolution. This creates a vibration at 2x the input frequency. Thus, in the case of strain wave drives, it is often necessary to use a larger drive to maintain the same load capability. This introduces additional weight and cost to the application.

Due to the patented technology implemented, the M-DRIVE technology does not exhibit a 2x torsional resonance like strain wave drives.

The elasticity of the flexible spline inside a strain wave drive can introduce mechanical resonances and instabilities. The workaround for this is to use a larger drive size since it

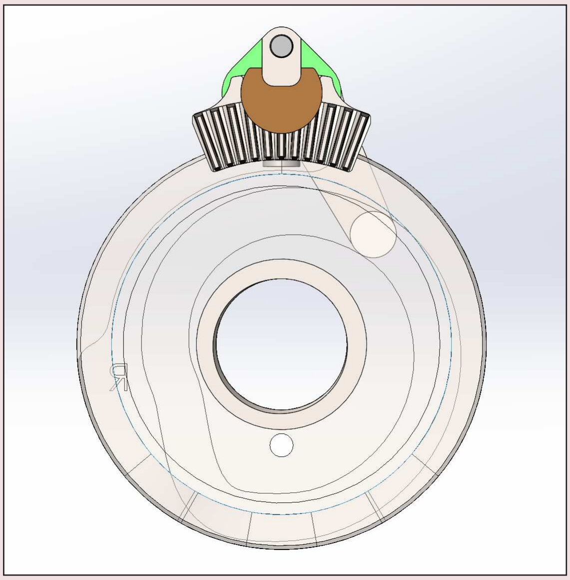


Figure 1: Rocker arm mechanism for ML1000.

INSIDE M-DRIVE TECHNOLOGY

THE M-DRIVE IS a speed reducer utilizing CAM technology to generate precise, programmable motion of the individual gear pads. The unique combination of radial and axial CAM profiles within a single component provides for the unique motion while ensuring correct timing of all internal parts. The CAM profiles, which are generated utilizing Motus Labs' propriety software, can be adjusted for multiple motion profiles, making the M-DRIVE readily adjustable for various applications. In addition to providing large contact surfaces for optimized rigidity and longevity, the patented technology allows for high reduction ratios in a single stage.

improves torsional stiffness. This again introduces unwanted weight and cost to the overall application it is used in.

NEW AUTOMATION APPLICATIONS

Advancements in technology applications require that all components within an automation system, including the drive mechanism (*see Figure 1*), be evaluated and viewed in a discriminative light to ensure new applications are promoting innovative technologies.

M-DRIVE technology delivers not only in precision but promises to provide higher torque density while maintaining the compact, lightweight structure demanded by customers (*see Sidebar II: The Importance of Torque Density*).

Furthermore, through the ability to use various materials, the M-DRIVE can be used in a wide variety of unique applications where weight is a critical factor or where non-magnetic materials are necessary, such as those found in the medical industry (MRI machines for one) and the semiconductor industry (for precision handling of sensitive semiconductor components). Technology-enabled reductions in the need for precision machining lowers the cost of manufacturing, which translates into cost savings for the user.

Other applications that would benefit from M-DRIVE technology include aerospace and defense for satellites, UAVs, and antenna motion control; automation in everything from packaging to pick-and-place operations; construction for 3D printing of large structures; climbing robots for inspection; and demolition equipment. Increased reliability, lightweight, smaller footprint and high precision are critical to these and many other applications across all industries.

SETTING PACE FOR SMART MANUFACTURING

The M-DRIVE was designed with Industry 4.0 in mind. AI-driven robots and automation applications require smart actuators that require smart gears. The new architecture positions Motus Labs as an enabling technology leader for new applications in adaptive robotics and motion control as the industry shifts from traditional automation to smart manufacturing.

THE IMPORTANCE OF TORQUE DENSITY (GEARED SOLUTIONS)

ELECTRIC ACTUATORS NOT only add weight along an articulated robot arm, but they also have torque and speed limits that impose additional dynamic constraints. Further, the useful life of a robot depends on the extent to which each actuator operates at or near its torque ratings. Cumulative damage theory offers some means of quantifying how much wear a robot arm will sustain in real time as it executes a given trajectory. The dynamic performance as well as fatigue wear of a hypothetical dual-link robot arm are examined in the context of actuator torque density—the actuator's torque-to-mass ratio. The results show that the expected wear to the most stressed joint is approximately inversely proportional to the actuator's torque density. The model also suggests how expected robot life under one or more predefined trajectories could be used as an additional constraint in robot arm design and actuator choice.

Articulated robot joints employ actuators that come with torque ratings that are given in the context of actuator lifetime (e.g. 50 Nm for 1 billion input cycles). Thus, there is an unavoidable intersection of robot design with reliability engineering: the value of torque available from a robotic joint is only meaningful in the context of how many times it can be applied. In the paper mentioned below, we attempt to examine actuator weight and available torque as not only dynamic constraints (Section III) but also as key drivers for the useable lifetime of the robot (Section IV). We offer a reliability component that could augment the standard robot dynamics model and offer some observations about how such a model could, among other things, aid in optimizing the design of robot arms intended for a limited set of tasks. (***Click*** to read the technical paper: *"Impact of Actuator Torque Density on Expected Robot Life – A Dynamic Model"*)