Cycloidal Geartrain in Use Efficiency Study

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cycloids aren't nearly as awesome as all these papers said

I. INTRODUCTION

As robotic applications flourish in our modern world, there is a need for highly customized actuators for a number of different use cases. In many cases, the demand is for high reduction, high torque, compact, and low backlash systems to allow them to fit into the actuators being developed for these robotic systems. This need is true in spaceflight applications as well. Many robotic systems are being developed with the need for compact, high reduction drives. A notable recent example includes the Curiosity rover from NASA's Jet Propulsion Laboratory [**?**] that uses (X) Harmonic Drives [**?**]. However, in higher torque scenarios, Harmonic Drives cannot withstand the application, therefore, a different geartrain must be used. In this high load, high reduction, compact design case, Cycloidal Drives provide an interesting design potential.

A. *Cycloidal Drive Background*

Cycloidal drives were proposed as early as 1956 by Botsiber and Kingston [1]. The premise of this design leverages the trochoidal motion of a plate eccentrically spinning on a shaft and interacting with pins on the outer diameter to induce motion. The basic shape can be seen in Fig **??**. This geartrain design has been used in industry for high torque, high shock load applications for many years [**?**]. However, in many of these applications, all of the interacting surfaces use needle roller bearings to transmit load. This allows for higher efficiency and load carrying capability but it also increases mass and size for a given design need. In the robotic industry, groups are striving to reduce the mass and size of these actuators while still achieving the high reduction and load capabilities. The primary method to do this is to eliminate many of the rolling elements at the interaction points between the wobble plate, housing pins, and output pins. This allows for very compact and strong designs to be considered.

*TODO: See if I should credit NASA/Bill for funding

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Many papers have been presented on the subject of this style cycloidal drive theoretical design [2] [3] [4], designing with machine tolerances [**?**], contact and stress analysis [5], and performance characteristics such as torque ripple and backlash [6] [7]. These works lay a solid foundation to a designer for the equations and design considerations to take while designing a cycloid. However, there has been very little work done in the area of in-use characteristics aside from the theoretical calculations and models.

Many of these papers did calculations for the efficiency, Malhorta and Parameswaran calculated between 98% and 88% efficiency for designs [8] and Sensinger predicted 95% [9]. Later, Sensinger and Lipsey performed a short one and a half hour study on the efficiency of a cycloid test article [**?**] showing efficiencies in the 40% range for fused roller designs, which are designs in which the housing pins are part of the housing, and 60% for pin designs, in which the pins are separate from the housing. In addition, Hsieh did work verifying the stress present in the drives in simulation and in use [7].

The aim of this work is to show the in-use efficiency and TODO Torque ripple over an extended duration test of a similar design intended for much higher torques using three wobble plates to show application to a high torque, compact actuator design. First, the authors will detail the actuator design in Section **??**. Second, a description of the experimental setup and procedure is provided in Section **??**. Finally, the results and analysis of this high torque actuator and its implications are presented and discussed in Section **??** and Section **??**.

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B. Units

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$$\alpha + \beta = \chi \tag{1}$$

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use (1), not Eq. (1) or equation (1), except at the beginning of a sentence: Equation (1) is . . .

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- The subscript for the permeability of vacuum ?0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter o.
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- There is no period after the et in the Latin abbreviation et al..
- The abbreviation i.e. means that is, and the abbreviation e.g. means for example.

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TABLE I: An Example of a Table

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Three	Four

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Fig. 1: Inductance of oscillation winding on amorphous magnetic core versus DC bias magnetic field

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity Magnetization, or Magnetization, M, not just M. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write Magnetization (A/m) or Magnetization A[m(1)], not just A/m. Do not label axes with a ratio of quantities and units. For example, write Temperature (K), not Temperature/K.

V. CONCLUSIONS

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

APPENDIX

Appendixes should appear before the acknowledgment.

ACKNOWLEDGMENT

The preferred spelling of the word acknowledgment in America is without an e after the g. Avoid the stilted expression, One of us (R. B. G.) thanks . . . Instead, try R. B. G. thanks. Put sponsor acknowledgments in the unnumbered footnote on the first page.

References are important to the reader; therefore, each citation must be complete and correct. If at all possible, references should be commonly available publications.

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