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Fatigue Testing a Laminated Compliant Clutch

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Compliant mechanisms derive motion from flexible segments, rather than from joints. A BYU student, Nathan Crane, used compliant design concepts to develop a prototype centrifugal clutch.[1] Manufacturing considerations led to a design incorporating many layers rather than a single solid piece.[2] Further testing verified the engagement RPM and torque capacity of the clutch.[3]

Due to the flexural nature of the clutch, fatigue failure represents a concern to manufacturers interested in licensing the clutch. Often, small cracks develop and grow due to repeated stresses. A sudden catastrophic failure may result.

The clutch layers would likely be produced by blanking and stamping. At high volumes, this is the cheapest process available. Also, beneficial compressive stresses are formed in critical areas which resist the formation of fatigue cracks. However, the initial costs of a stamping die are prohibitory to prototype production. BYU does have an EDM setup capable of producing the geometries needed. EDM normally leaves cracks near the surface, which are removed by shallow trim passes. With trim cuts, the fatigue characteristics approximate those of a stamped part.

Developing the testing apparatus with Derek Wright took more time than anticipated. For that reason, we first tested models made in 2002. They were built with EDM, but without trim passes. They had very poor fatigue results, lasting a few hundred cycles, though the other parameters gave good results. One clutch was manufactured and tested successfully this year, and others are ready for testing. The model tested gave several insights into how the clutch can fail with fatigue.

The tested clutch ran for over 12,100 cycles, less than the marginal value of 50,000 cycles. Several possible reasons could explain this. This first clutch was off 0.005 inches due to a programming error. According to the model in use, this could cause a difference of 10 ksi in the stress of critical areas. Subsequent clutches have been made with the correct dimensions that should perform better. Also, the experimental loading cycle could be substantially different from that experienced during normal operation. In fatigue testing it is better to overestimate the loading cycle to allow for user error, so this should not undermine the results.

Wear of both the drum and the clutch contributed to failure. The flexible members on the outer edge of the clutch were visibly thinner and the drum had grooves etched where the clutch contacted it. Even though the outer members became thinner, the inner members ultimately failed. The distance between the clutch and the drum increased with increasing wear. This greatly increases the stresses in the inner members since they flex more than the outer members.

A design improvement under consideration focuses on the inner segments. Bending them towards the center, opposite from the current setup, adds length and distributes the stress better. The analytical model will need to be adjusted for this change to see if the torque and engagement RPM will be similar to the current model.

Continuing work on the clutch includes production and testing of more specimens to better establish the fatigue life and account for stochastic variation. The worn drum has been replaced with a production drum currently used in consumer products.

Also to be tested are clutch models that don't leave the layers unattached. A simple way to join the layers is with a spot welder, readily accessible in the Department. Joining the layers may reduce wear by eliminating gouging and spreading the contact force evenly among all sections. The drum will also be less likely to become grooved.

Even thought the first test was unsuccessful, the design should still prove valid. Further testing is being carried out to verify that assumption.

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[1] Crane, Nathan B. Compliant Centrifugal Clutches: Design, Analysis, and Testing. Brigham Young University. Provo, Utah. 1999.

[2] Herring, Aaron L. High Production Manufacturing Considerations for Metallic Compliant Mechanisms with Long Thin Beams. Brigham Young University. Provo, Utah. 2001.

[3] Wright, Derek. The Effectiveness of Multiple-Layer Fabrication of the Floating-Opposing-Arm Clutch. Unpublished. 2002.