Summary

The planetary-harmonic transmission is a bold and innovative design that thrives in today's market. In a world where everything is being made smaller and more efficient, the planetary-harmonic excels. With its capability for a small footprint and high gear ratios, the planetary-harmonic transmission combines form and function in a very innovative way. This quality is especially valuable in robotics (and specifically, FIRST Robotics) where size restrictions are of the utmost importance.

Planetary-Harmonic Transmission

The planetary-harmonic transmission has the capability of being an important competitor in robotics technologies. This innovative transmission combines two very well-known and tested designs into a sleek and efficient machine. The planetary part gives the transmission the ability to be very compact while the harmonic part allows for large gear ratios. Very seldom do both these options come together; engineers must choose one or the other. In the past, robots using traditional spur gear designs needed a fair amount of room to achieve an average ratio of, for example, 28:1, but now these or greater ratios can be realized in a much smaller footprint. While cost and the required amount of precision machine work are greater, the benefits of this design outweigh these drawbacks.

To truly understand the usefulness of this design, one must learn the workings of the transmission. While any gear ratios and materials can be used with this design, it is easiest to explain in specific terms. Therefore, the design specifications used in the 2009 FIRST Robotics Competition will be used to describe the design. The transmission is based upon two center gears that are one tooth different from each other, a 35-tooth and a 36-tooth gear. (See Figure 1) These would be considered the *sun* gears in a traditional planetary system. There is then one 20-tooth gear meshed with each of the center gears. These *planet* gears are connected through a “double” 20-tooth planet gear. This consists of two 20-tooth gears pinned together and offset from the sun gears so as to mesh only with the planet gears and not the two sun gears. This set of three planet gears is repeated three times (each gear is 120° apart from another of its kind) to create a balanced planetary design (See Figure 2).

All of these gears are sandwiched between two outer plates. One of these plates is a large 120-tooth gear that is driven by a 96-tooth gear pinned to the CIM motor shaft. (See Figures 3 and 5) The 35-tooth gear has the output or drive shaft attached to it and the 36-tooth gear has a square tube attached to its hub which is fixed into the drive assembly housing to keep it stationary at all times. (See Figure 4) The planet gears are then centered on bolts that are fixed to the outer plates. Driving the outer plates causes the 20-tooth planet gears to “orbit” around the sun gears and since the 36-tooth gear is fixed, the 35-tooth gear is driven at an approximately 35.5:1 gear ratio.

Planetary gearing is any gear system that has three or more *planet* gears revolving around a center *sun* gear. The planetary-harmonic design fits this description perfectly, except with a slight twist. Instead of having simply one sun gear and three planet gears, this design incorporates two sun gears and nine planet gears. It also eliminates *annulus* or outer ring gear seen in traditional planetary designs.

Harmonic gearing is a slightly less recognized design, but is nonetheless just as useful. A harmonic system works on the principle of gear teeth meshing only once or twice per revolution, which is generally done with a flex spline and wave generator. The planetary-harmonic design is not harmonic in this sense, because all the gears are continuously meshing. However, the design gains its harmonic designation from the fact that the two sun gears offset one tooth from each other every revolution. In a traditional harmonic design, the flex spline and circular spline would offset one or two teeth from each other for every revolution of the wave generator. In the planetary-harmonic design, the 35 and 36-tooth gears offset one tooth for every one revolution of the outer plates.

Combining these two designs creates a very versatile transmission. The planetary part of the transmission provides the capability of a very small footprint. The harmonic component allows the transmission to be designed with relatively large gear ratios while maintaining the small form factor set by the planetary part. This combination of large gear ratios and small form factors makes the planetary-harmonic design a perfect contender in the field of robotics.

While it is evident that this design has many advantages over a spur gear transmission, it is not as clear as to how combining the planetary and harmonic designs is better than using a single design separately. Reasonably sized planetary transmissions are most useful for ratios of around 10:1 and must be made into multi-stage transmissions to achieve greater ratios. This can lessen the effectiveness of the planetary design in that it becomes larger to accommodate the multiple stages and larger gears needed to handle the torque levels put out by the motors (CIM motors in the case of FIRST Robotics).

While harmonic transmissions can easily produce gear ratios of 50:1 and greater, they have a large amount of overhead. Harmonic transmissions require a flex spline and wave generator to be fabricated as well as a circular spline. These items cannot be found in a typical gear catalog and must be custom made or ordered. While this can be done, it greatly increases the cost of the project. While the planetary-harmonic design requires its own precision machining and careful assembly work, it is still significantly cheaper and easier to manufacture than a strictly harmonic design.

When designing a component for a robotics project, size is a major concern. Almost always, there are size restrictions that limit the amount of space any one component can take up in a project, as is the case with the FIRST Robotics competition. There are many other pieces that must be incorporated into the robot: electronics, handling mechanisms, and scoring mechanisms to name a few. Therefore, it is important to design each mechanism as small and as versatile as possible to accommodate the other components that may require more space.

This is where the planetary-harmonic transmission excels. This design is able to fit into the same space of a traditional spur gear transmission with a ratio around 25:1, but is able to achieve up to double that ratio. This gives anyone using the design a huge advantage in that a wide range of gear ratios can be chosen without any concern for an oversized drive train. The planetary-harmonic design does become less effective with lower gear ratios (20:1 and under) since a spur gear system would be about the same size (figuring two or at most three stages) and would be much easier to manufacture. The planetary-harmonic thus is most efficient when used to achieve large gear ratios.

A final attribute that makes the planetary-harmonic a very versatile transmission design is the ease at which it can fit into almost any drive and steering configuration. The transmission can be used in a system where it is fixed such as a tank or skid style steering in which at least one wheel on each side of the robot is driven, but remains in the same orientation. Alternatively, it can be used in a design that requires the entire wheel and gearbox assembly to be rotated, such as Ackerman steering (traditional car steering). (See Figure 5.) Since the transmission has no housing of its own, it can easily be fitted into any housing needed to accommodate the motor and wheel assemblies.

The planetary-harmonic transmission is a design that is perfectly in step with the technologies of today's world. At a time when engineers are looking to create mechanisms that are smaller and more efficient, this design carries the torch, combining these most necessary qualities into a very versatile and impressive machine. While the design does call for a decent amount of machine work and financial resources, the benefits gained through having a design that can fit almost any drive train, size restraint, or required gear ratio are so great that these disadvantages become almost insignificant. The planetary-harmonic transmission is certainly an innovative design that has a great future in the field of robotics.

Works Cited

Epicyclic Gearing. February 08, 2009. Artec Machine Systems. 25 April 2008 <http://www.artec-machine.com/documents%20free/epicyclic-gearboxes/an_overview/epicyclic_gearing.htm>

Harmonic Drive. April 2009. Harmonic Drive, LLC. 25 April 2008 <http://www.harmonicdrive.net>.

William H. Haverdink. “Transmission.” World Book Encyclopedia. Chicago: World Book, Inc. 1996.

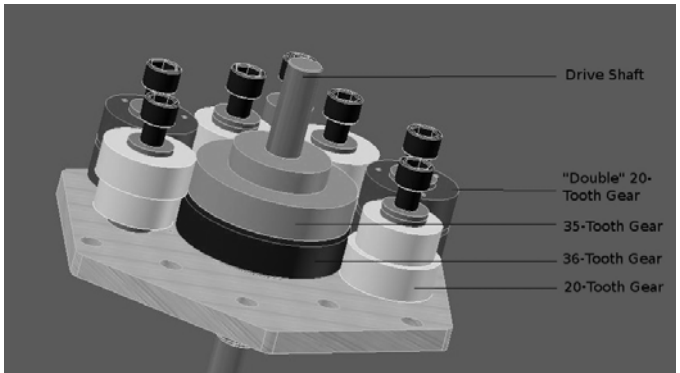

Figure 1: Transmission Cutaway

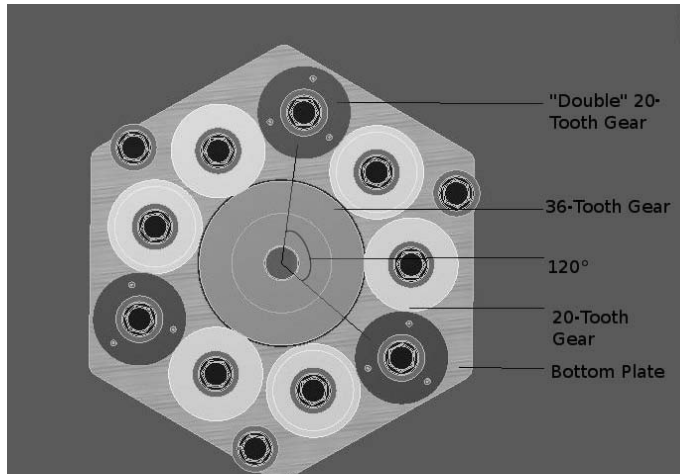

Figure 2: Top View of Transmission

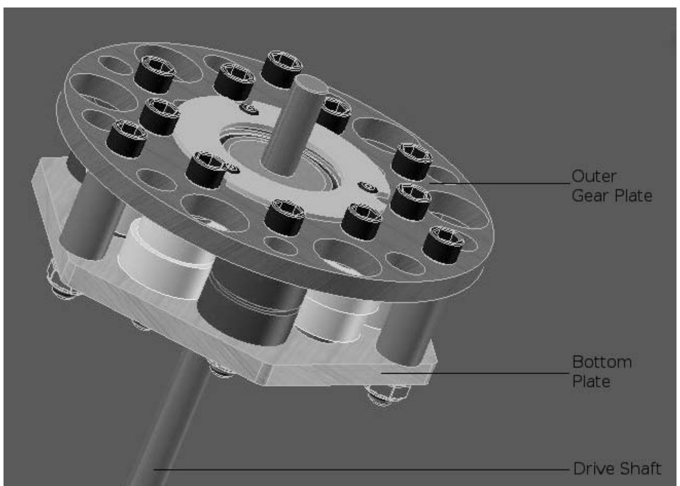

Figure 3: Full Transmission

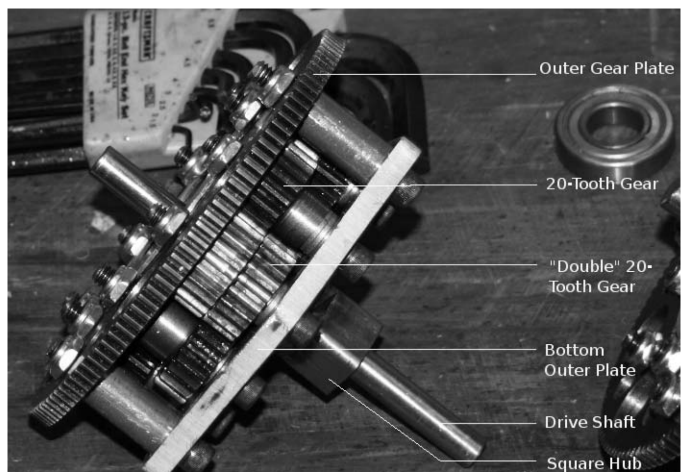

Figure 4: Completed Transmission

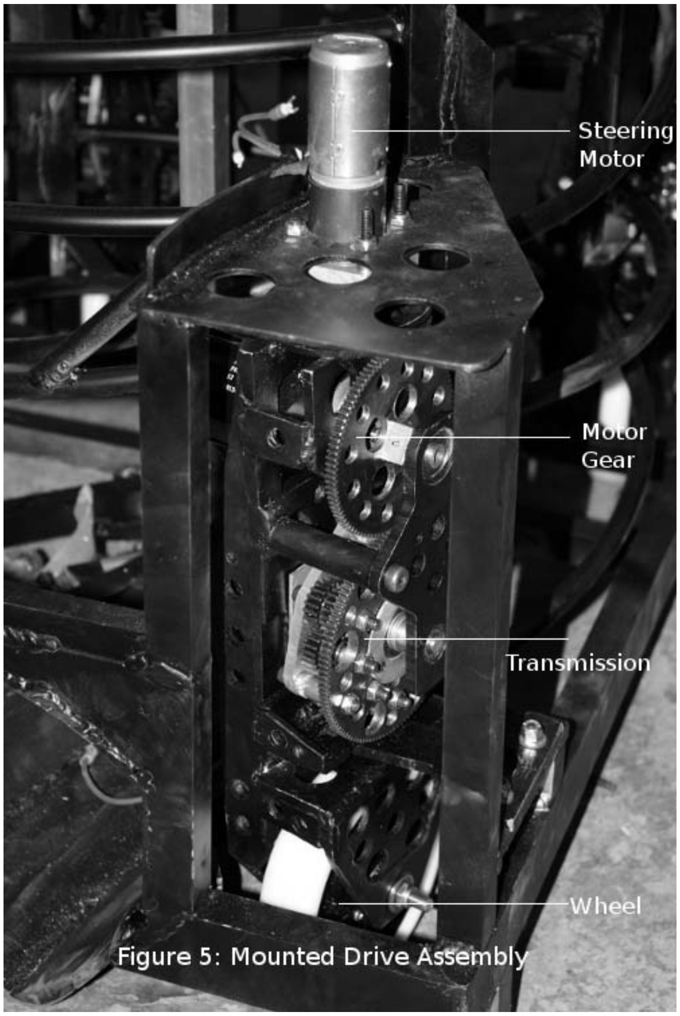

Figure 5: Mounted Drive Assembly