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Technical Support Package

Gear Bearings and Gear-Bearing Transmissions

NASA Tech Briefs
GSC-14207

National Aeronautics and
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Technical Support Package

for

GEAR BEARINGS AND GEAR-BEARING TRANSMISSIONS
GSC-14207

NASA Tech Briefs

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Gear Bearings and Gear-Bearing Transmissions

A. Prior Art

A state-of-the-art planetary gear system uses Helical Planetary Gears with two sets of ball bearings and it drives its output off a carrier. In driving off the carrier, mechanical advantage is already sacrificed as is some efficiency. The Gear-Bearing system transmission is superior (greater mechanical advantage through elimination of the carrier) and has greater efficiency by eliminating its losses. This transmission system uses two sets of ball bearings to locate and stabilize the operation of the gears. This takes up space and the interfaces make for a weaker system.

The Gear-Bearing approach reserves a small section of real estate on an orthogonal surface of the gear teeth and geometrically sets the timing on these to perform the bearing function. In so doing, a lot is gained. Using one, two, or more separate bearings requires separate interfaces and separate attachment/detachment. These tend to rattle and are flexible and so weaken the structure. To save space, relatively small ball bearings are used frequently. In Gear Bearings, no separate interfaces are required. They are already in place as part of the Gear Structure. Also the bearings are, essentially, variations of large spin bearings and, so, have inherently large load bearing capabilities. Furthermore, they are located very near the gear action so they avoid having to deal with a great deal of offset torque.

The second system comprises Harmonic Drives that have been a recent standard for very large mechanical advantage gear systems in compact packages. These systems have been around for approximately 10 years. They come in two main types, a pancake type (short axial length) and a cup type (with a larger axial length). They operate by means of a wave generator which rotates and, in so doing, periodically pushes a flexible spline (with teeth) radially outward in two diametrically opposite places. When the spline deflects outward, its teeth push against the sides of the teeth of the output ring, causing the output ring to move to one side. As the wave generator turns, the points of flexible spline contact turn with it and the output ring moves with it as well.

There is generally one less tooth in the output ring than in the flexible spline so as the flexible spline makes a complete cycle, the output ring moves a total of one (1) tooth width in rotation. The pancake versions are not as easy to lubricate and are not as efficient as the cup types though they are more compact. The cup types are more efficient but not as compact. Both types are expensive and a bit flimsy. The flexible splines tend to fail by stripping. Gear-Bearing transmissions will have efficiencies as good as the best Harmonic Drives and will rival them in having a high mechanical advantage. They will be tougher. They will not strip. They will also be simpler and cheaper and will work efficiently in a compact pancake configuration. Gear-Bearing transmissions will also be better than Harmonic Drives in providing mechanical advantages in very small packages. Harmonic Drives have great speed reduction but, this advantage falls off in small packages.

Carrier-Less, Anti-Backlash Planetary Drive System, U.S. patent 5,409,431, April 25, 1995, by John M. Vranish used a similar arrangement of Planets, Rings, Sun and Speeder to produce a high mechanical advantage planetary transmission. The Speeder Sun Gear concept was proven, but extra bearings were required. This greatly complicated things and made the system too large. Also, the system was anti-backlash via spring loading which also complicated the system. Anti-backlash is frequently not needed and is very expensive.

B. DISADVANTAGES OF PRIOR ART

These are listed above but; are summarized here.

Current state-of-the-art planetary transmissions.

- Use a carrier that restricts mechanical advantage (requiring a second stage in some cases).
- Use of the carrier which reduces efficiency.
- Use separate ball bearing systems to stabilize and locate gear components and output/input drives. These are bulky and introduce interfaces which reduce the strength, simplicity, and stiffness.
- Tend to be parts intensive and expensive.

Harmonic Drive transmissions.

- Use a flexible spline that will strip and fail under load.
- Pancake versions are inefficient; cup types are bulky.
- Expensive and parts intensive.
- Do not achieve high mechanical advantage in small packages. In small diameter packages, it still must advance one tooth width per revolution and for small packages that is a large portion of the circumference.

Carrier-Less, Anti-Backlash Planetary Drive System.

- Too expensive and complex because of anti-backlash features.
- Too expensive, bulky and structurally not sufficiently rigid because of the extra bearing races and their interfaces.
- Did establish Speeder Sun Gear function/capability.

C. COMPONENT PARTS AND MODE OF OPERATION

The invention starts with a new component concept; specifically a component that performs both Gear and Bearing functions in a single component using two or more orthogonal surfaces simultaneously. There are two versions: (1) Roller Gear Bearings (Figure 1) and (2) Phase-Shifted Gear Bearings. The invention extends beyond these new components to innovative ways of combining them into elementary systems and, beyond this, to innovative ways of combining the systems into more complex systems. Finally, the invention returns to discussing still more innovative variations of the basic component Gear Bearings. We will first discuss Roller Gears, then Phase-Shifted Gear Bearings. Following this we will examine the use of Helical gears in Gear Bearings and then examine, in some detail, two very promising superior performance fixed-ratio transmissions based on Gear Bearings.

1. Roller Gear Bearings

We will first discuss Roller Gear Bearings (Figures 1, 2, 3). Spur Roller Gear Bearings (Figure 1), consist of a Spur Gear which has a Roller coaxially mounted on its top. The diameter of the roller is set equal to the Pitch Diameter of the Spur Gear Teeth. The tops of the Spur Gear Teeth are crowned at the point where they interface with the Roller. The apogee of each of the crowns is set to match the Tooth Pitch Diameter and the Roller Diameter. The same concept can be directly extended to adding a Roll Race coaxially mounted on the top of a Ring Gear such that the diameter of the roll race is set equal to the Pitch diameter of the Ring gear Teeth. The tops of the ring Gear Teeth are crowned at the point where they interface with the Roll Race.

The Roller Gear components, Planets, Sun and Ring can be assembled in a planetary system as shown in Figure 2. This Planetary Roller Gear System is, inherently, held together without further props or structures. As can be seen from Figure 2, if a Planet is pushed down its teeth will slide with respect to the ring gear and the sun but, its Roller will be blocked by the upper surface of the teeth of the ring gear. If the Planet is pushed upwards, the Roll Race of the ring gear will block the upper surface of the teeth of the planet. If the Sun Roller Gear is pushed down, its Roller will be blocked by the upper surface of the teeth of each of the three planets and so the planets will be taken down with it. However, these planets will each, in turn, be blocked by the Roller Ring Gear so, ultimately, the Sun Roller Gear cannot be pushed down. Likewise, the Sun Gear Bearing cannot be pulled up. The Planetary Gear-Bearing System is held together firmly. Figure 3 shows more detail on how Roller Gears interact with each other. Figure 3a shows Roller Spur Gears interacting with Roller Spur Gears (the case where the Sun Roller Gears are interacting with the Planet Roller Gears). Figure 3b shows Roller Spur Gears interacting with Roller Ring Gears (the case where the planets are interacting with the Ring Gear). Figures 3a and 3b show that the Spur Gear on Spur Gear case is essentially the same as the Spur Gear on Ring Gear case in terms of matching speeds for both the roll and gear surfaces. Figure 3c shows that by crowning the tops of the Spur Gear with the apogee of the crown at the same radial distance as the Roller and Tooth Pitch Diameters thrust bearing contact must occur at the apogee point and so speed matching can be achieved for simultaneous and/or individual contacts between interfacing Rollers, Gear Teeth and thrust bearing Tooth Tops/Roller Bottoms. This means, then, a Planetary Roller Gear System will perform with great efficiency and strength. Also, the addition of the rollers must, inevitably, greatly improve the accuracy with which the gears mesh. The rollers precisely set gear locations with respect to each other. On the other hand, the gears act as a highly efficient and precise caging/carrier mechanism for the Rollers. The cumulative result is a superior system that is also very simple and low cost.

2. Phased-Shifted Gear Bearings

Phase-Shifted Gear Bearings (Figures 4, 5, 6) will now be discussed. Figure 4 shows a pictorial of Phase-Shifted Gear Bearings for the simple Spur Gear case. It shows a Spur Gear in which the upper gear half is rotated with respect to the lower gear half so that the two halves are exactly out of phase with respect to each other. That is, the teeth of the upper gear half are positioned above the gaps between teeth of the lower gear half. Thus, it could mesh with a Phase-Shifted Gear Bearing just like it. As the one Gear turned and drove the other, both halves would be continuously contacting each other but; in different phases of contact. If, as in the case of Figure 4, the lower gear half teeth are bevelled and extended slightly in between the teeth of the upper gear half and if, simultaneously, the upper gear half teeth are bevelled and slightly extended in between the teeth of the lower gear half for both Phase-Shifted Spur Gear Bearings, the bevelled tooth surfaces will contact each other much in the same manner as a four (4)-way thrust bearing at the same time the spur gear surfaces of the teeth will engage in conventional spur gear motion. The two motions can be timed so as to maximize efficiency, strength and smoothness.

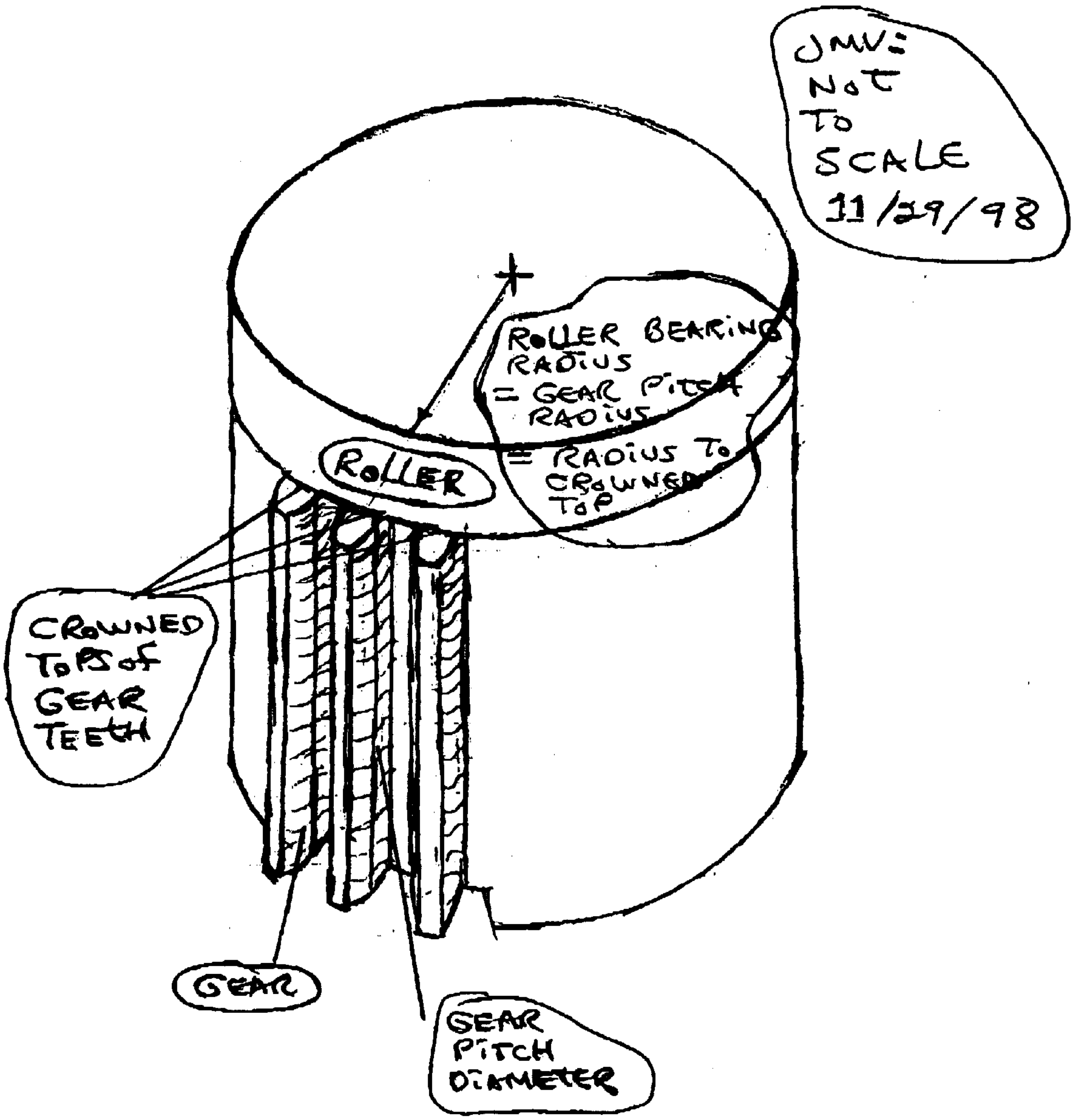

Figure 1

Roller Gear

(To preserve technical authenticity, all illustrations have been reproduced directly from hand-sketched laboratory notes.)

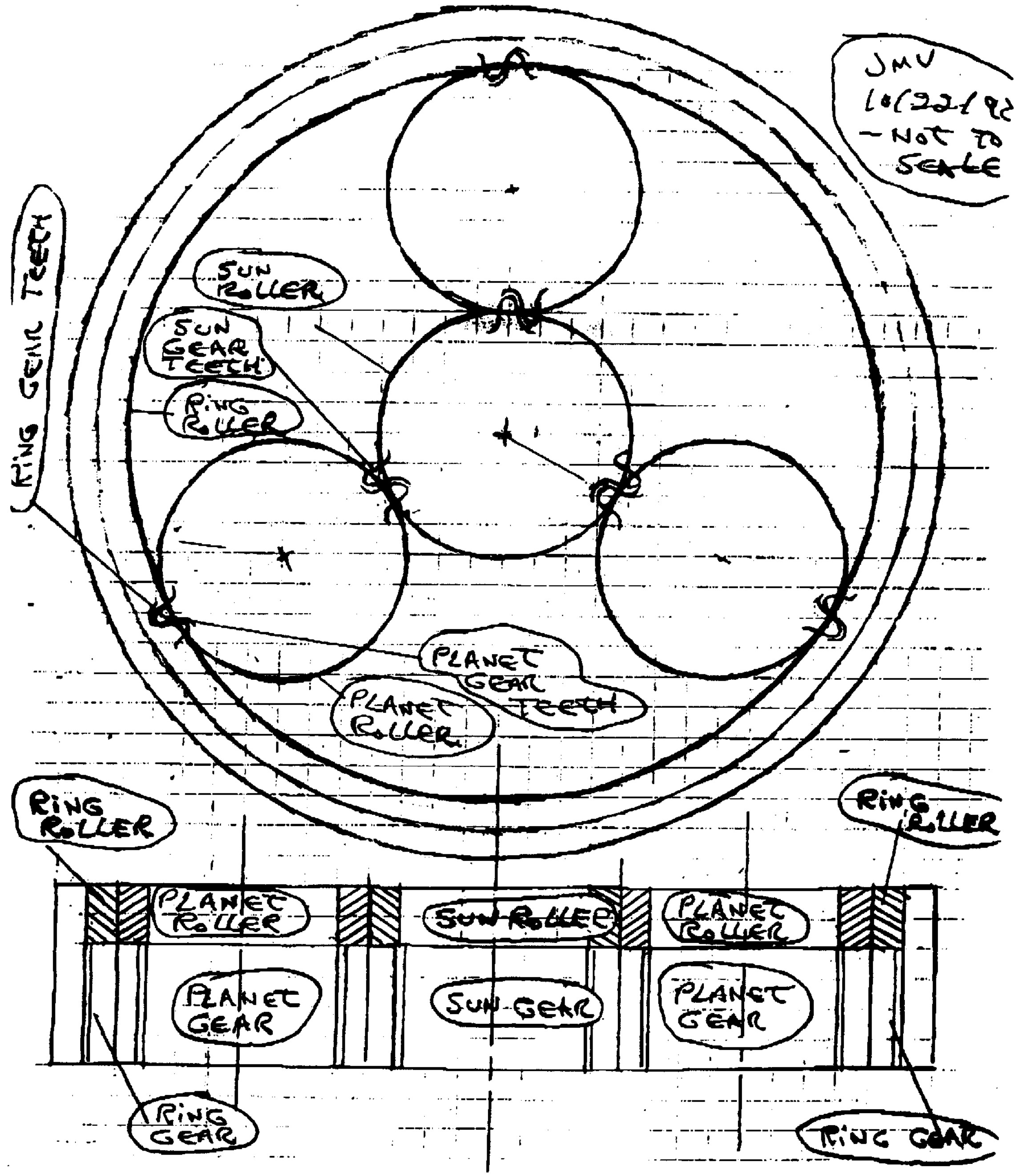

Figure 2

Roller Gear Assembly/Stabilization Technique

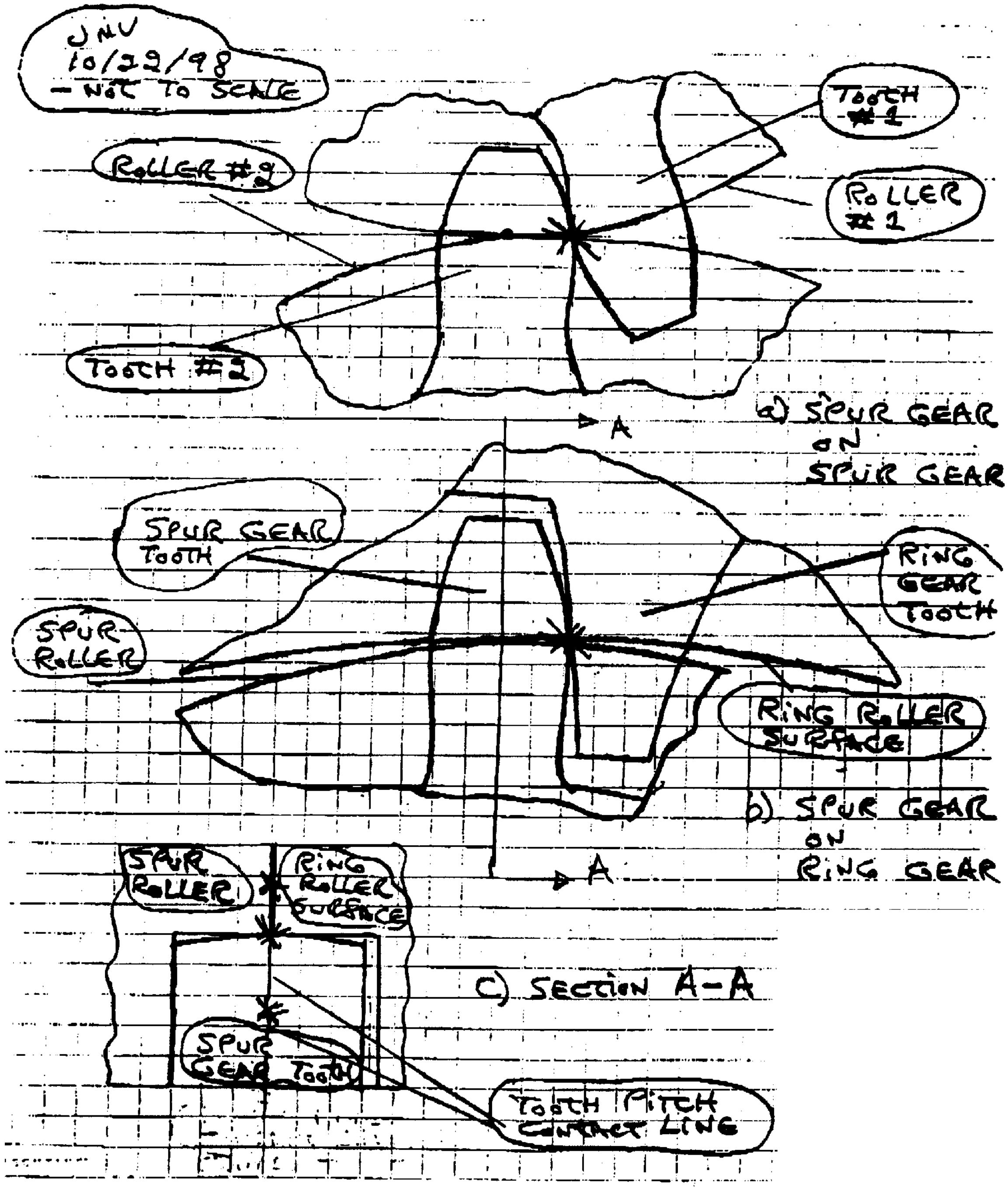

Figure 3

Roller Gear Detail

Figure 5 shows that Phase-Shifted Gear Bearings inherently stay together very much in the same manner as roller Gear Bearings described above. Figure 6 shows detail in how the bevelled surfaces and gear contact surfaces are timed and angled to provide optimum bearing strength, directionality and efficiency for Spur Gear-Bearing contact. Figure 7 shows similar detail for Ring Gear-Bearing contact. In each case, the bevelled surface contact is defined as a point (by slightly crowning one of the two contacting bevelled surfaces) and is timed to match speeds at the gear tooth pitch diameter, assuring efficiency and smoothness of operation.

In each case, the bevelled angle θ_b is set to optimize four-way bearing directionality and the amount of crowning tines bearing strength. In all cases the bearings will be very strong. The bevels of the upper gear half form the upper half of the four-way thrust bearing and those of the lower half form the lower half of the four-way thrust bearing. During any instant of time, the lower gear half will engage a minimum of one (1) bevelled surface and the upper gear half will engage a minimum of one bevelled surface. Thus a minimum of one upper half and one lower half of the four way thrust bearing will be engaged at all times and the system will work as a built in four-way Spin Bearing (all be it a little bit digital in motion). It should be very strong because its smallest radius is that of the Planet or Sun and that is very large, indeed. Figures 4, 5, 6, 7 show that the bevels are set so that all contact points are at a common axial position on the Planet. This optimizes smoothness of motion and makes the system very compact.

3. Helical Gear Bearings

Helical Gear Bearings (Figure 8) will now be discussed. It is not difficult to imagine a Roller Gear Bearing (as shown in Figure 1) in which the Spur Gear is replaced by a Helical or Herring Bone Gear but nothing else is changed. The same timing issues and geometries that worked for the Spur Roller Gear Bearing would apply in these new cases. Phase-Shifted Helical Gear Bearings require a little more careful thought (Figure 8). However, upon closer examination, as we phase-shift the upper and lower halves, we see that the same concept works as was used for Spur Phase-Shifted Gear Bearings; only the Gear Teeth are Helical. The Bevelled Bearing Surfaces are not effected.

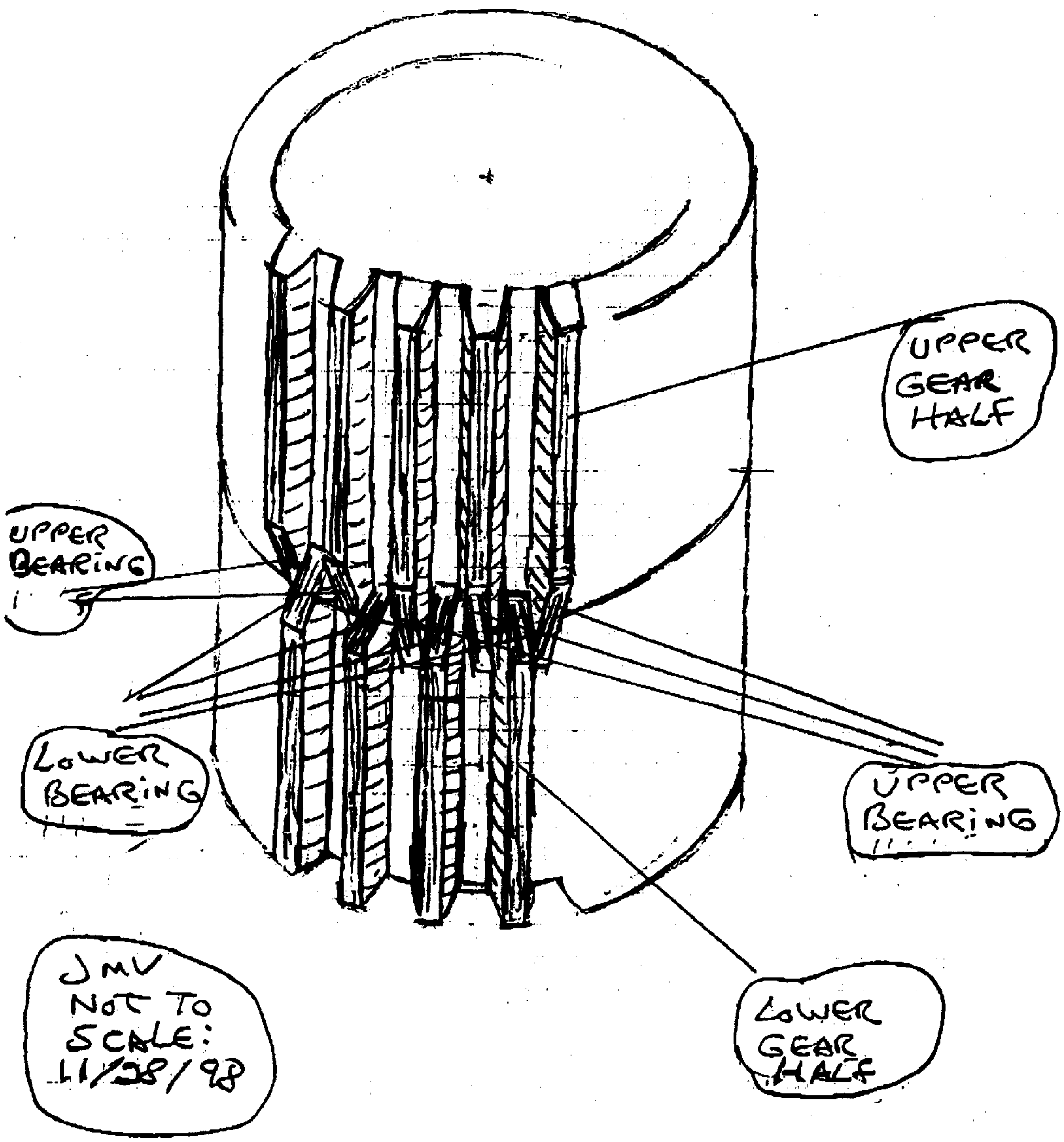

Figure 4

Phase-Shifted Gear Bearings

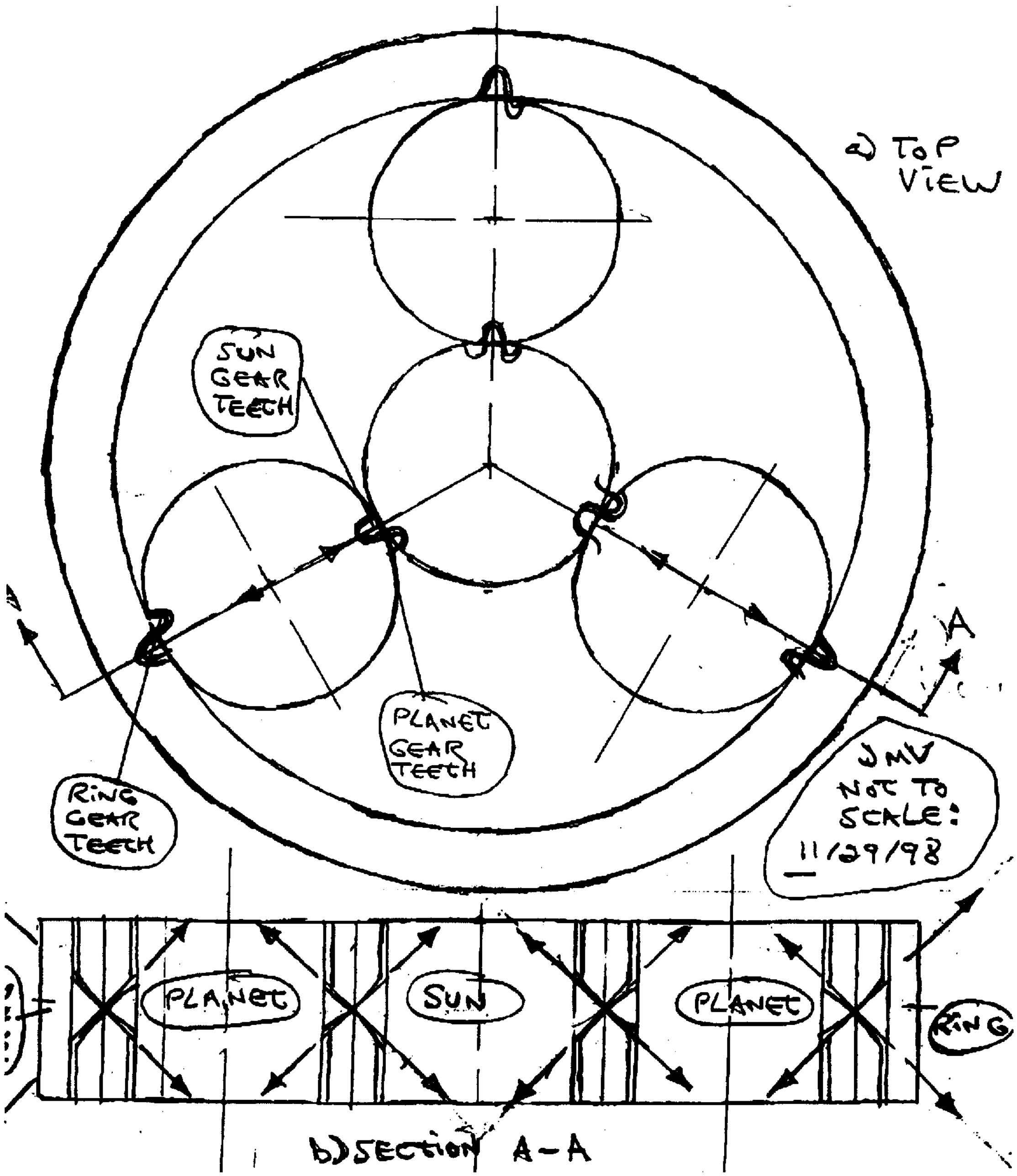

Figure 5

Phase-Shifted Gear-Bearing Stabilization Technique

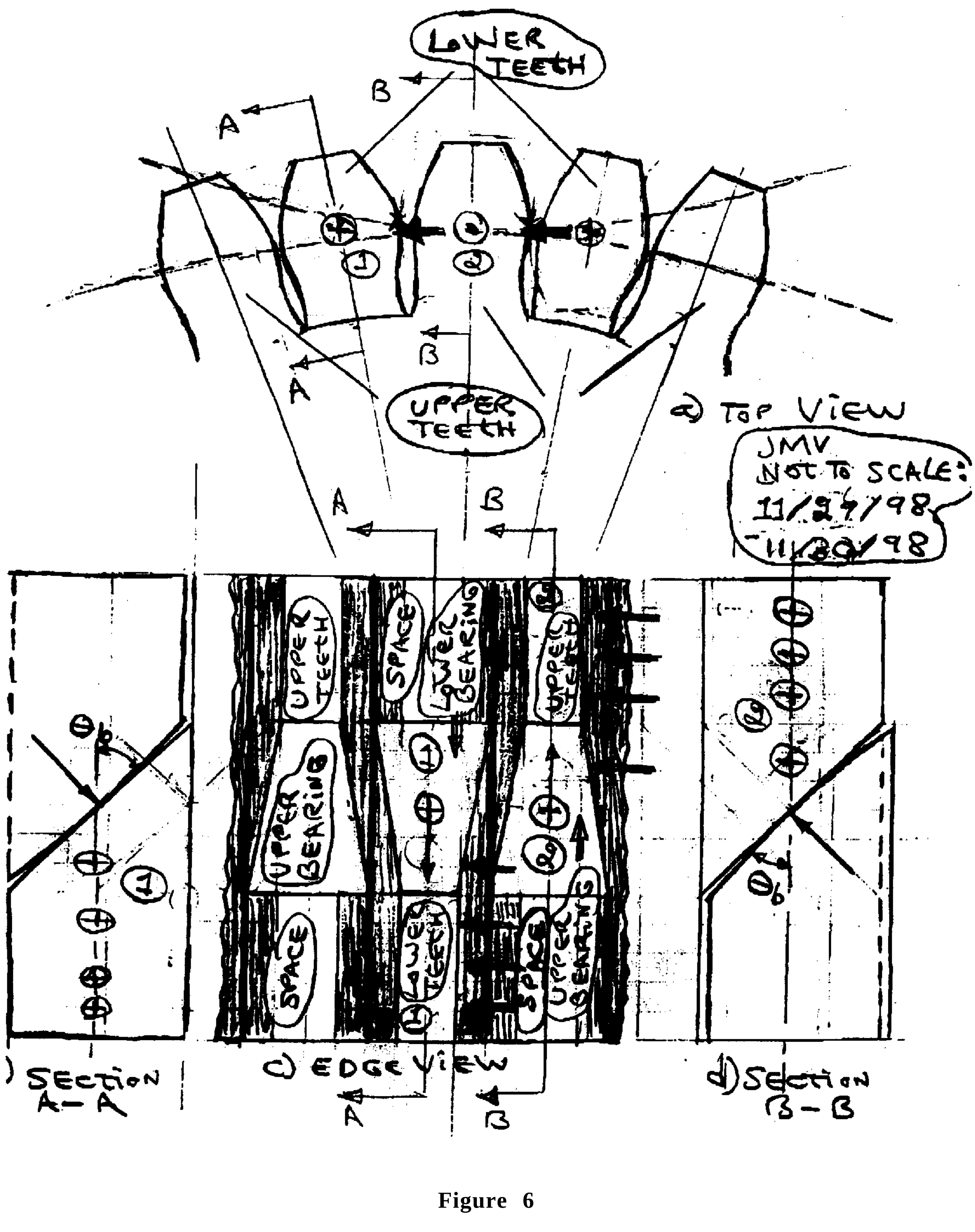

Figure 6

Phase-Shifted Gear Bearings (Spur Gears)

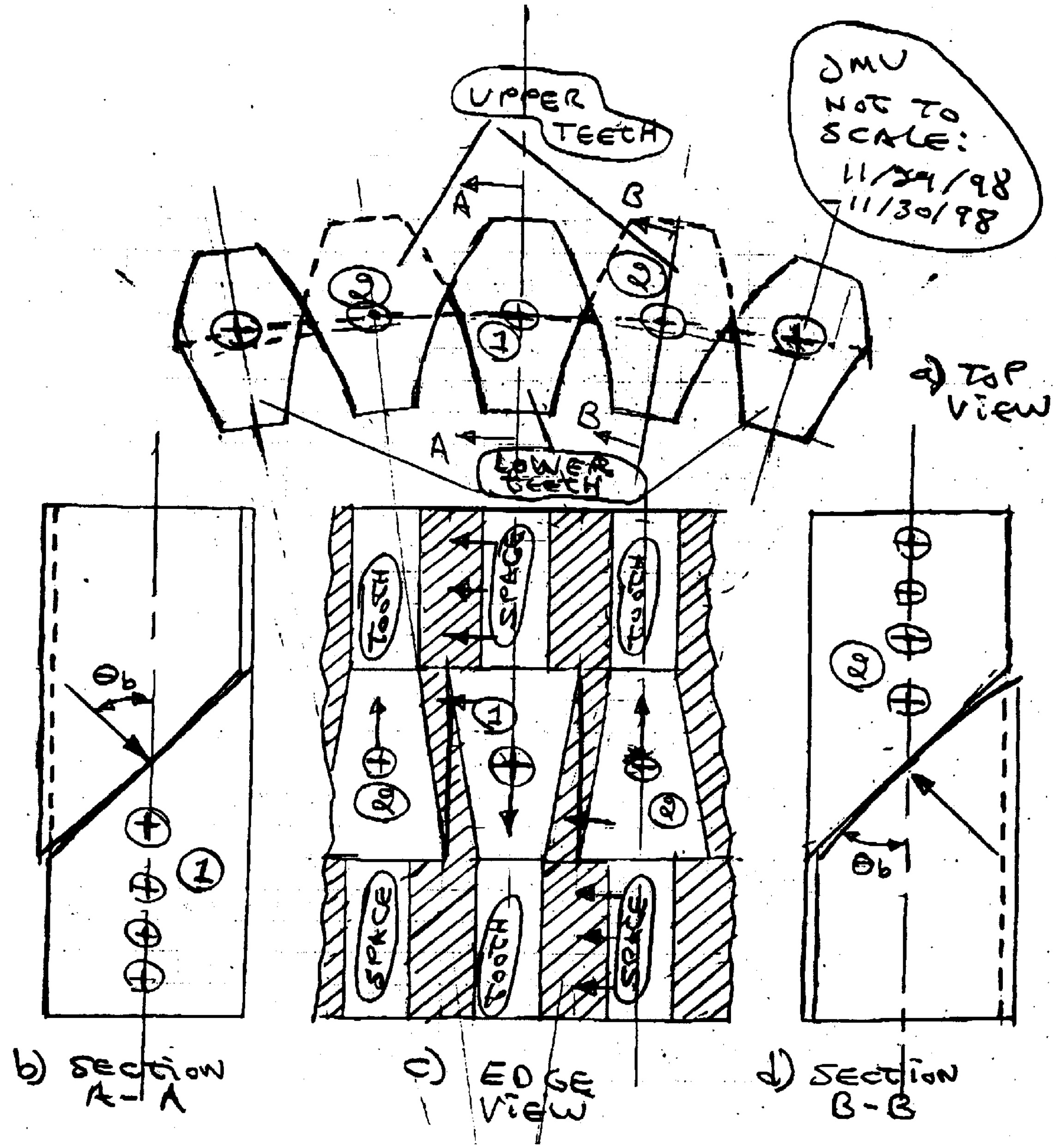

Figure 7

Phase-Shifted Gear Bearings (Ring Gears)

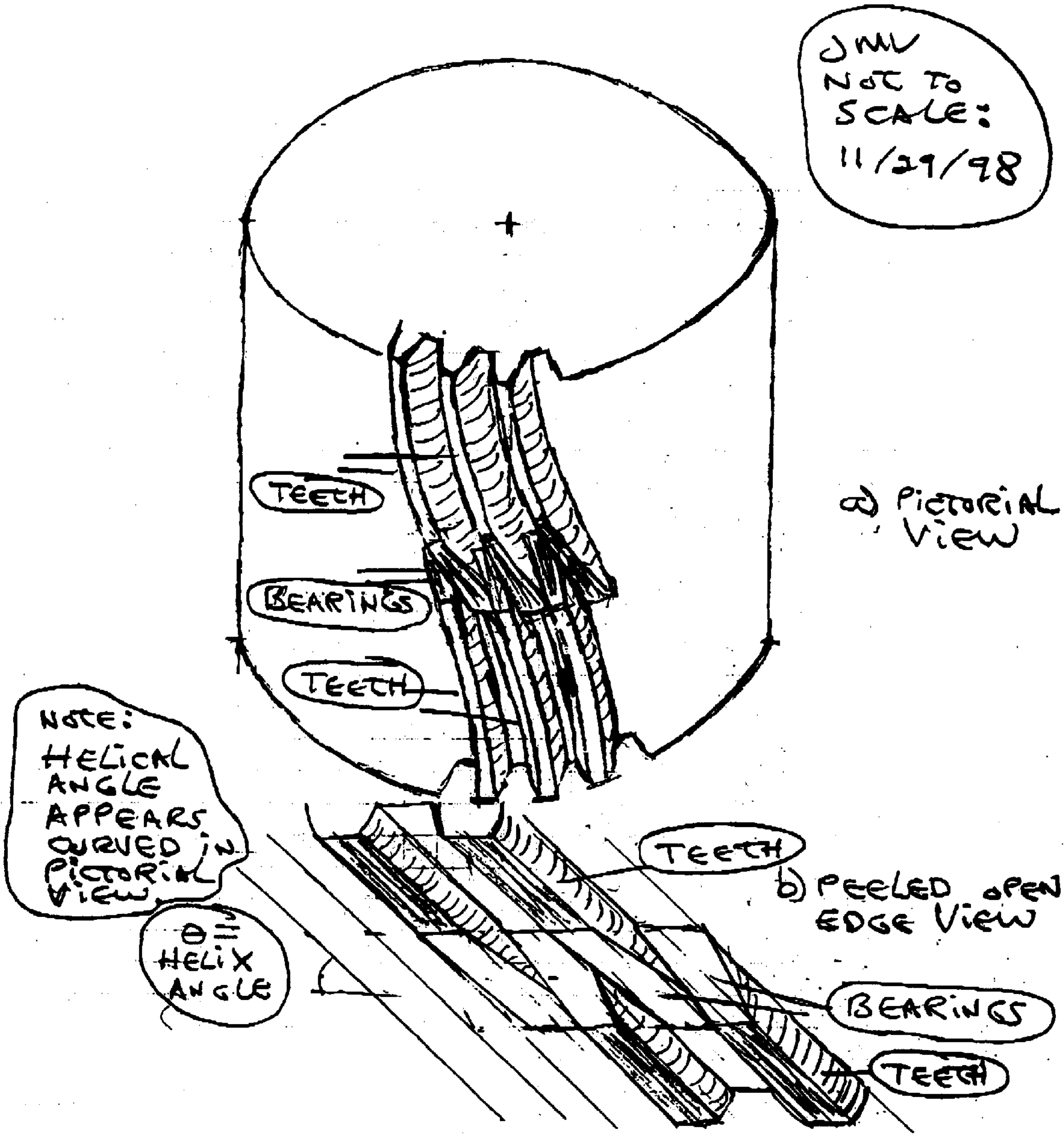

Figure 8

Phase-Shifted Helical Gear Bearings

4. Gear-Bearing Transmissions

The number of variations on the Gear-Bearing theme are endless but; only two (2) will be discussed here (Figures 9, 10). These two (2) are fixed mechanical advantage transmissions which show great promise in being strong, compact, very efficient, carrierless, simple and capable of great speed reduction. The two concepts are functionally very similar but; one uses Roller Gear Bearings and the other uses Phase-Shifted Gear Bearings.

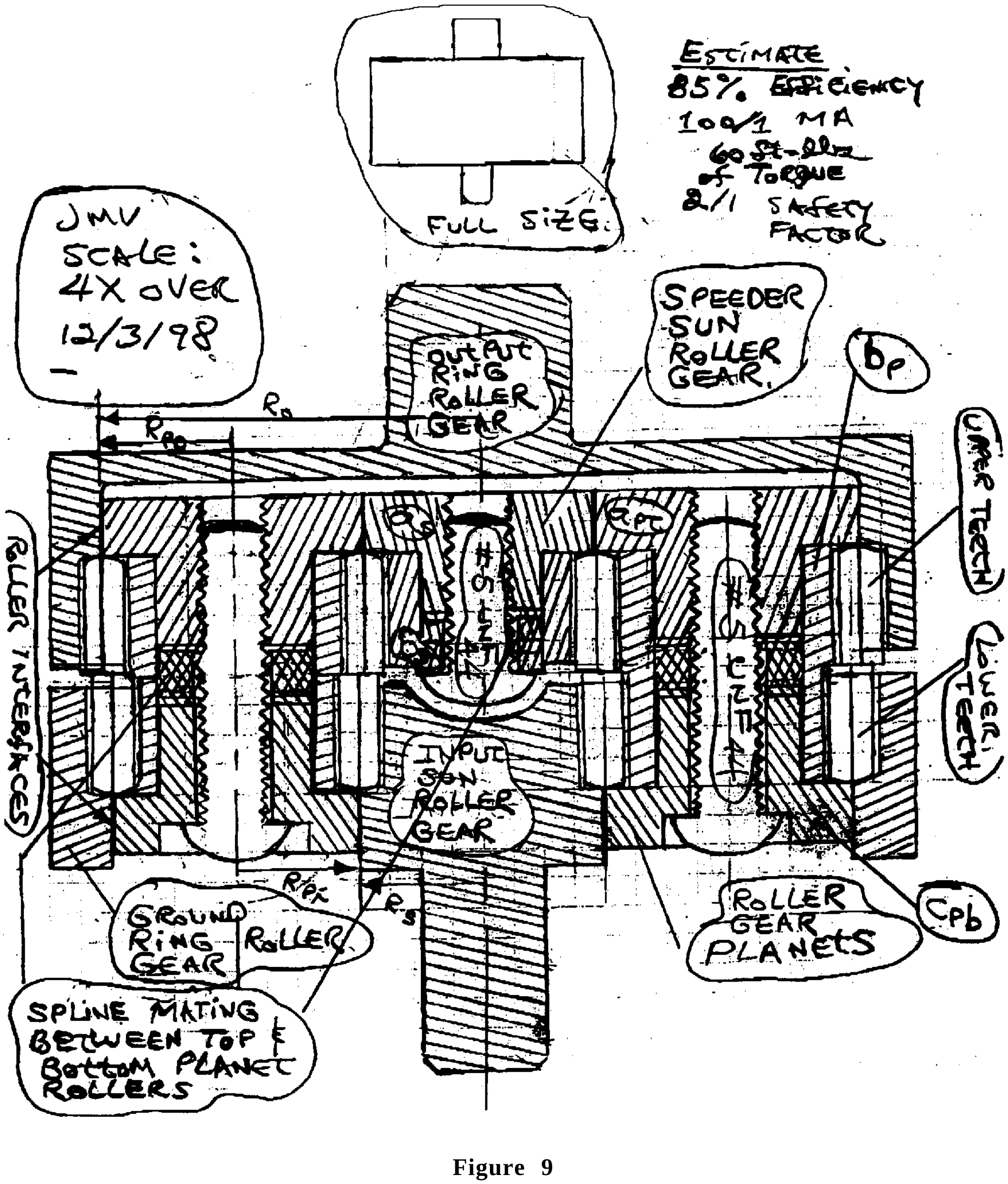

Figure 9

Roller Gear-Bearing Planetary Transmission

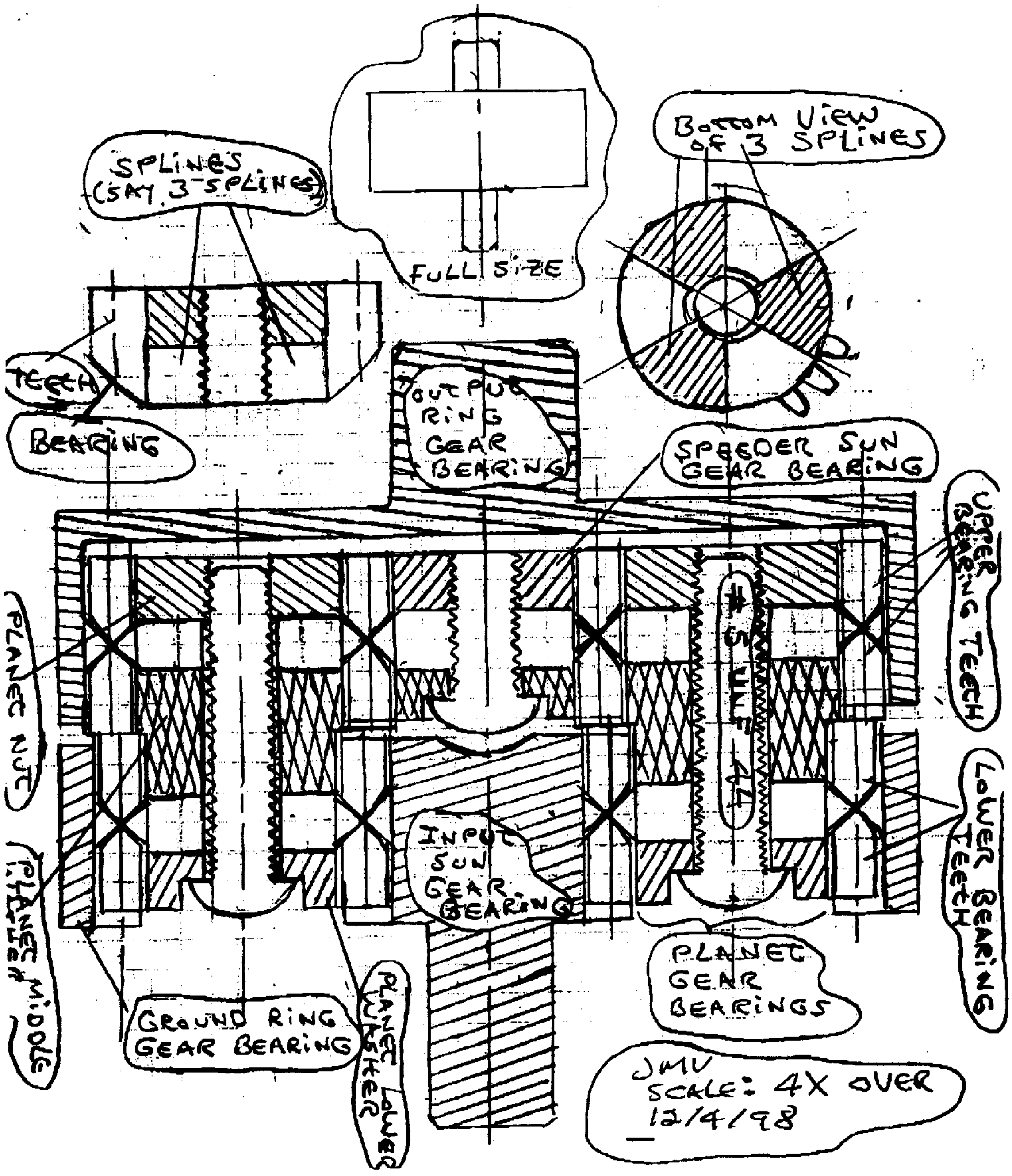

Figure 10

Phase-Shifted Gear-Bearing Planetary Transmission