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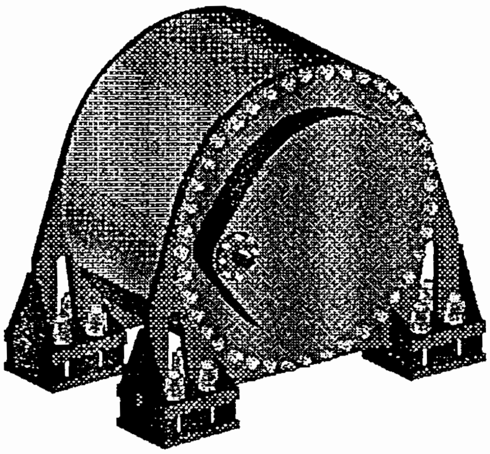

HIGH HORSEPOWER PLANETARY GEAR BOXES FOR REDUCED COST AND IMPROVED EFFICIENCY IN SUGAR CANE MILL APPLICATIONS

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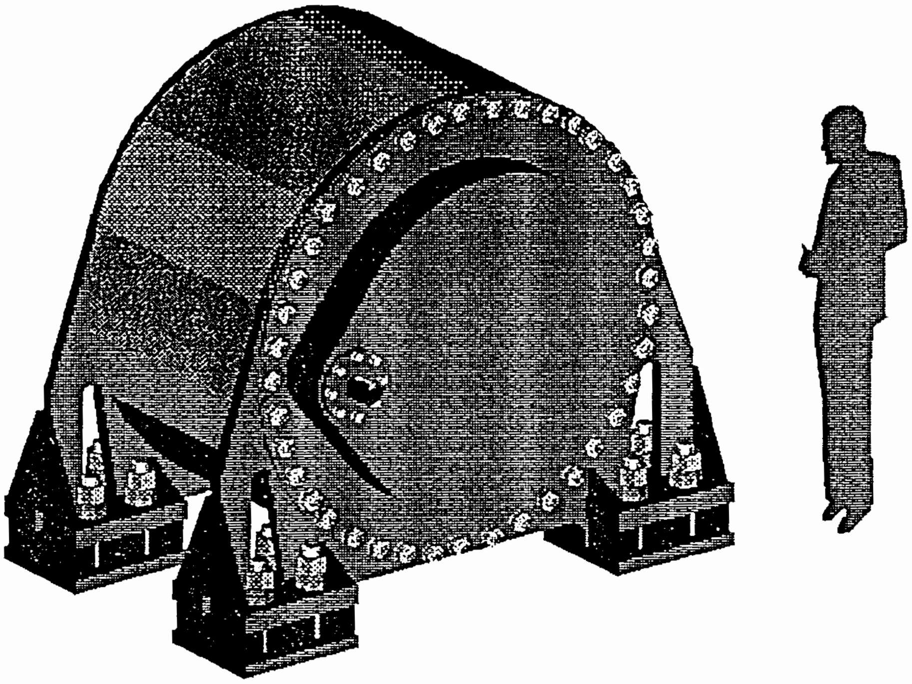


ABSTRACT

The planetary type speed reducing gear box is more adequate for transfer of high torque or high horsepower because there are six pairs of teeth carrying the load simultaneously rather than one pair as is normally the case in a parallel spur or helical reducer, or two pairs as in a herringbone parallel reducer. A planetary that has three planet gears will ensure equal load distribution at the planet to ring gear meshes. This analogy is similar to the three legged stool that will not rock regardless of how uneven the floor may be. This self aligning feature also makes it less sensitive to installation misalignment.

Because the planetary output torque is generated by the sum of the forces at six gear meshes, the forces are smaller in magnitude and consequently the entire planetary gear box can be much smaller than a parallel reducer. A planetary gear box may be smaller than half of a parallel reducer, therefore, it can be designed more conservatively to provide a longer life.

Perhaps the most important reason to consider a planetary gear box may be that it provides superior performance for half the price.

INTRODUCTION

A planetary gear box has the advantage of being able to transfer a much higher torque or horsepower in a smaller space because it has five gears simultaneously transferring the torque as compared to two gears in a parallel reduction. The five gears are: one sun pinion, three planet gears, and one ring gear for each planetary. Another advantage is that the input shaft (sun pinion) is concentric with the output shaft (planetary carrier). This allows a simplified internal construction for a gear box that requires a large reduction ratio. Another significant advantage is the fact that a planetary construction which has three planet gears, the load automatically becomes equally distributed between the three planet gears thus ensuring good durability properties. Either the sun or the carrier or both must be floating and when this happens the load is equally distributed and the forces become equal in magnitude in the same way that a three legged stool will not rock on an uneven floor regardless of how uneven the floor is.

PLANETARY CONSTRUCTION

The planetary has three principal members: a sun pinion, a planetary carrier assembly which includes three planet gears, and a ring gear, as shown on Figure #1. Figure #2 shows the gears in mesh. The ring gear is stationary, the planetary carrier is the member that rotates the output shaft, and the sun gear is the input member. The reduction ratio of the planetary is given by the following equation:

(Sun Number of Teeth + Ring Number of Teeth) / Sun Number of Teeth

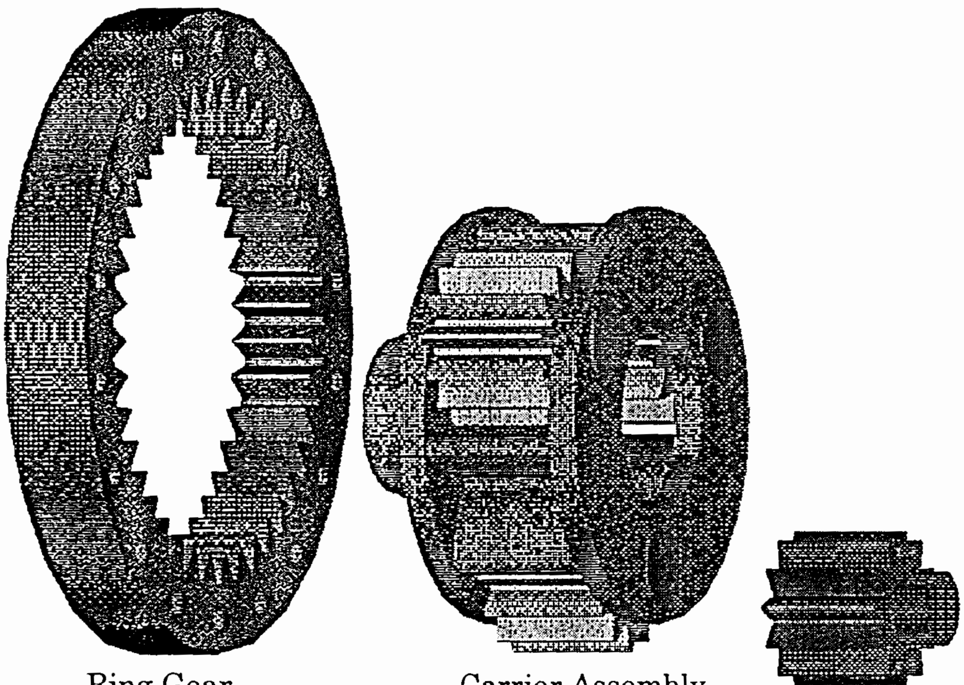


Figure 1

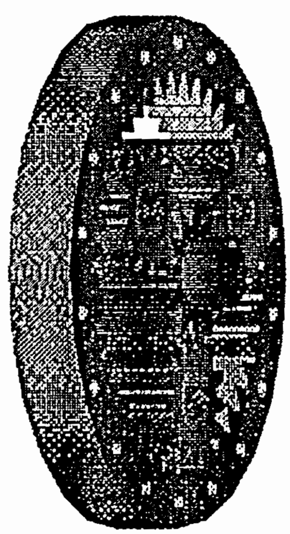


Figure 2

For the gear box shown in Figure #3 and #4, which is composed of two planetaries and a helical reduction, the entire equation that represents the total reduction ratio can be written as follows:

$$\text{Ratio} = (P/G) \times ((S2 + R2)/S2) \times ((S3 + R3)/S3)$$
$$= (180/13) \times ((152+15)/15) \times ((90+27)/27)$$
$$= 667.29$$

P = Input Pinion number of teeth
G = Input Gear number of teeth
S = Sun Pinion number of teeth
R = Ring Gear number of teeth
2 = Second Stage Reduction
3 = Third Stage Reduction

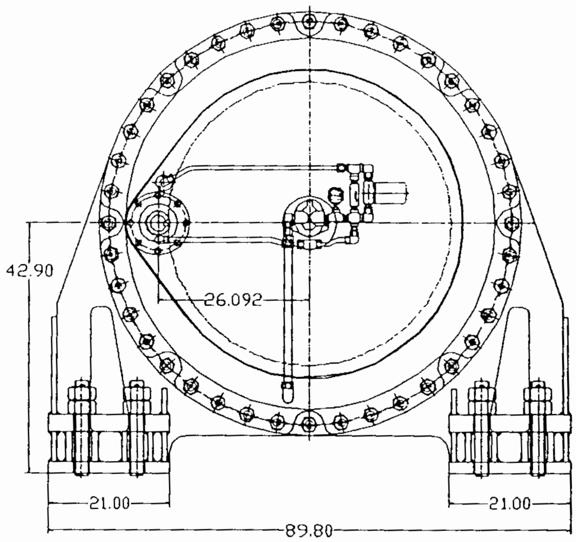


Figure 3

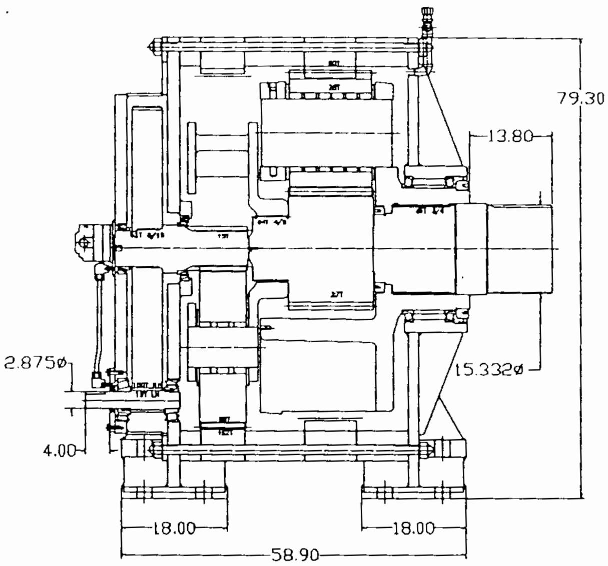


Figure 4

Figure #5 shows all of the components of a planetary, one sun pinion, three planet gears, three planet shafts, one ring gear, and one planetary carrier.

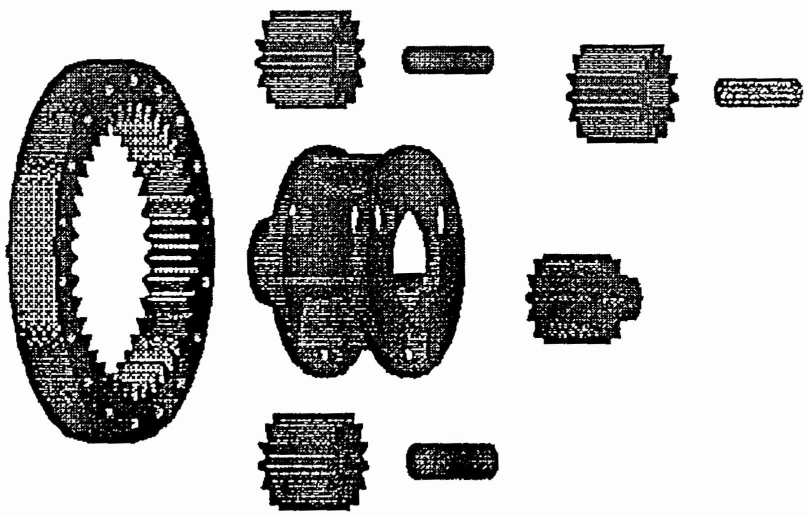


Figure 5

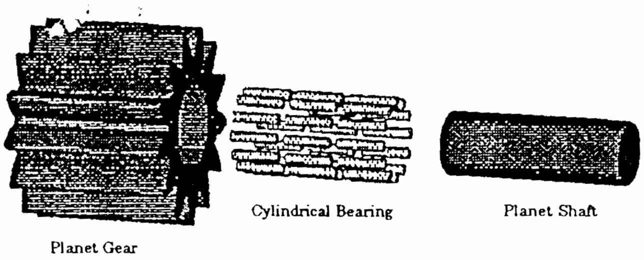


Figure 6

Figure #6 shows one planet gear, one planet shaft, and a triple row cylindrical bearing. To maximize the bearing capacity for long life, the shaft becomes the bearing inner race and the bore inside the planet gear becomes the outer race. The three rows of cylindrical rollers are used without a cage so that the number of rollers can be maximized and thus increase the bearing life. This is an economical bearing construction and the bearing life is calculated so that it will be as long or longer than the gear life. For example, if we look at Figure #4, the output planetary gears have a very large bearing and the bearing is constructed of six rows of rollers. The advantage of this construction is that not having individual bearing races for the inner or outer race we are eliminating the manufacturing eccentricity that would be inherent in six inner races plus six outer races. This eccentricity would de-rate the bearing life because the load could not be equally distributed as well as it can be distributed to each row of rollers when there is only one smooth cylindrical diameter common for the inner race and one smooth cylindrical diameter for the outer race that is common to all six rows of bearings.

As shown in Figure #4, the input set of gears is helical with ground teeth. It is more efficient, more economical, and more durable to make a parallel set of gears at the high speed input end rather than a planetary. Mechanical efficiency is increased because only two gears will operate at a high pitch line velocity where oil churning generates heat. The input torque is very low in comparison to the output torque(18,823 in-lb vs. 12,000 in-lb), therefore, it is more economical to make a helical gear set for the input. Also, having a fewer number of working components results in increased reliability. This helical gear set will be referred to as the first stage reduction. The second stage reduction, as well as the third stage, are planetaries.

The second stage reduction planetary has a ring gear of the same outside diameter as the third stage reduction which is also the output. The planetary gear box will be filled nearly half full with oil.

An oil lubricating pump is mounted on the input gear. It directs oil taken from near the bottom of the gear box through orifices which spray the four Timken tapered roller bearings on the input helical gear set as well as the gear mesh. The two planetaries will not need to be pressure lubricated because they will be partially submerged in oil. Every time the carrier rotates it will be lifting oil to the mesh with the sun pinion and will submerge each planetary bearing in oil. These bearings will be submerged in oil nearly half the time. Having only part of the gear box pressure lubricated increases the reliability. Whenever there are fewer things to go wrong, there will be fewer break-downs. In addition, there will be an air cooling fan over the input face to help dissipate the heat generated by the high speed input gear set.

The output pinion shaft, as shown on Figure #3, can be mounted at any angular position. The circular housing plate can be rotated to any angular position desired so that it would match the elevation of the power generating shaft.

FORCE DISTRIBUTION

Figure #7 shows the ring gear, the three planet gears, and the sun pinion. Each planet gear has two arrows on the teeth and each planet gear bore has one longer arrow. The two arrows on each planet gear, marked "F", designate the forces that act upon the teeth of the planet gear. The force near the center is the force from the input torque, marked "T". This force is generated at the sun pinion teeth and acts upon the planet gear teeth. Because the planet gear is mounted on an anti-friction bearing, an equal force is generated 180° away from the sun pinion gear tooth mesh. This is where the planet gear tooth meshes with the ring gear. At that point, the reaction force, marked "F", also acting by the ring gear upon the planet gear tooth, is equal in magnitude to the force near the sun pinion. The magnitude of the force seen by the planet gear shaft, marked "2F", is the sum of the two forces acting upon the planet gear teeth. This is the action and reaction sum of the forces acting on the planet gear. Because the planet gear shaft is mounted in the planet carrier and because there are three such planet shafts, the output carrier torque is proportional to the sum of those three planet bore reaction forces multiplied by the radius at which they operate.

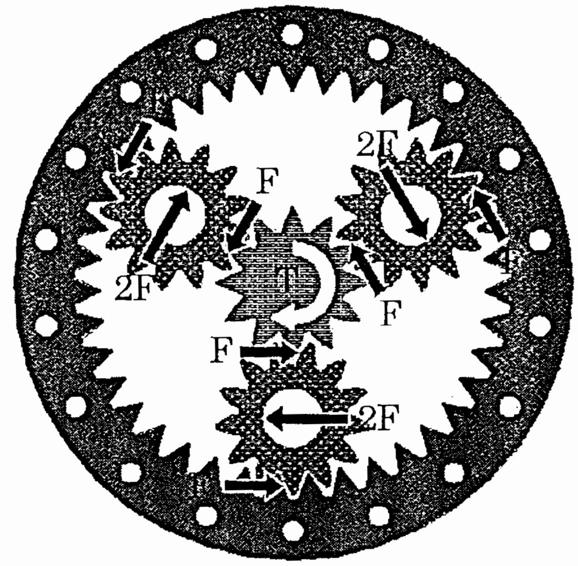


Figure 7

Planetary Carrier Torque = 2F x R x 3
F = Force at Planet Gear Tooth
R = Radius from Planetary Carrier Center to Planet Gear Center

This clearly shows that in a planetary there are six gear teeth in mesh simultaneously. At all times the forces on the teeth are equal in magnitude. This is the fundamental and principal advantage of a planetary construction gear reducer. Having six teeth carry the load simultaneously, the individual forces are lower than they would be if only one or two teeth carried the load, as is the case with spur and helical or herringbone parallel shaft gear sets.

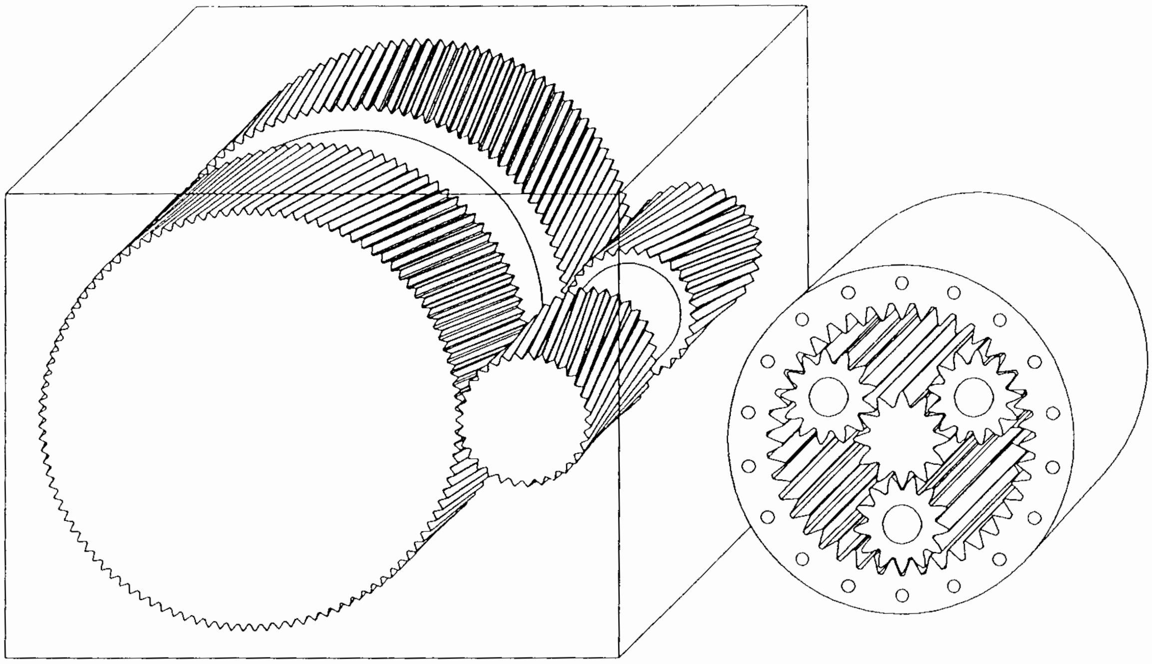
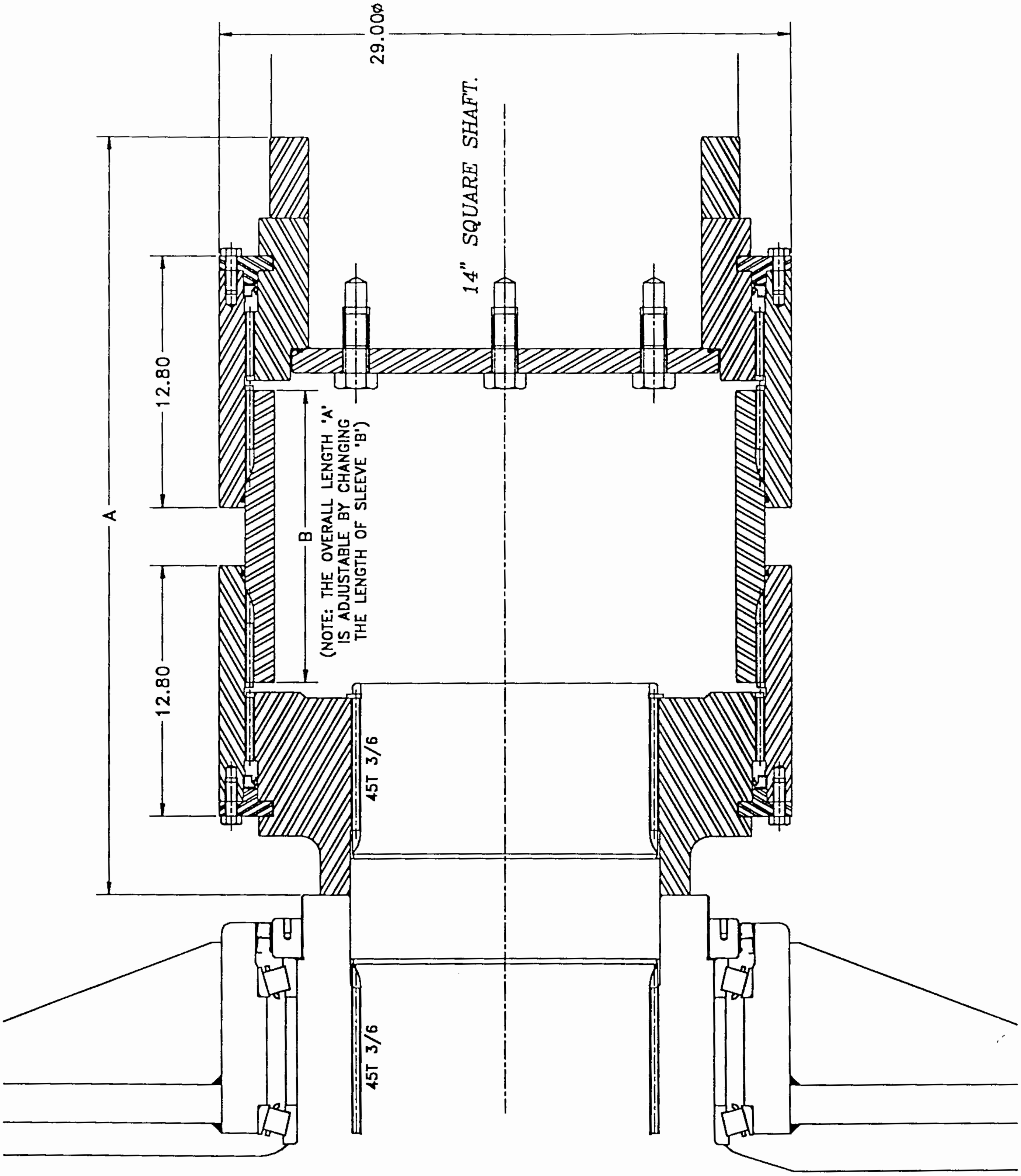


Figure 8

Figure #8 shows the output planetary construction as proposed in this gear box in comparison with a set of herringbone gears that would carry the same amount of torque at the same speed and with the same surface compressive stresses. For comparison purposes they are drawn in proportional dimensions. You may see that a rectangular box that would enclose the herringbone set of gears would have to be much larger than the outside diameter of the ring gear as shown on Figure #8. This illustrates that the planetary construction requires a much smaller operating space. The individual components of a planetary are also smaller than those in a parallel reducer. It may be seen that the sun pinion and the three planet gears are smaller in diameter than the herringbone pinion. The herringbone pinion is also nearly twice as long axially as the sun pinion and planet gears.

Because of the inherent ability of a planetary to achieve equal load distribution, it is not necessary to open the gear box to check the gear tooth load distribution as it would be in a large parallel reducer. The gear case for a planetary is not only smaller, but also much stiffer than the gear case for a parallel reducer. A planetary gear case is not susceptible to the amount of distortion due to mounting seen in a parallel reducer gear case, because in the planetary, the ring gears are also structural members.



Output Gear Coupler
for Sugar Mill Applications

Figure 9

CONCLUSIONS

A planetary gear box construction forms a high power density speed reducer. It is more economical to manufacture because all of the components are smaller in size and lighter in weight. This gear box has a total of twelve gears and twelve bearings. This planetary gear box is only 6' in diameter and 5' long. With an input of 4,000 RPM and an output of 6 RPM, this gear box has a total reduction ratio of 667:1. At a capacity of 1,200 HP and twelve million in.-lb. of output torque, the gear box has an AGMA durability factor of 2.66. For an AGMA durability factor of two, as is common in sugar mill applications, this gear box has an output torque rating of 16,760,000 in.-lb. For a sugar mill application this gear box will have a very long wear life. This gear box can be adapted to different turbine speeds simply by changing the ratio of the input set of helical gears. The two planetaries need not be changed.