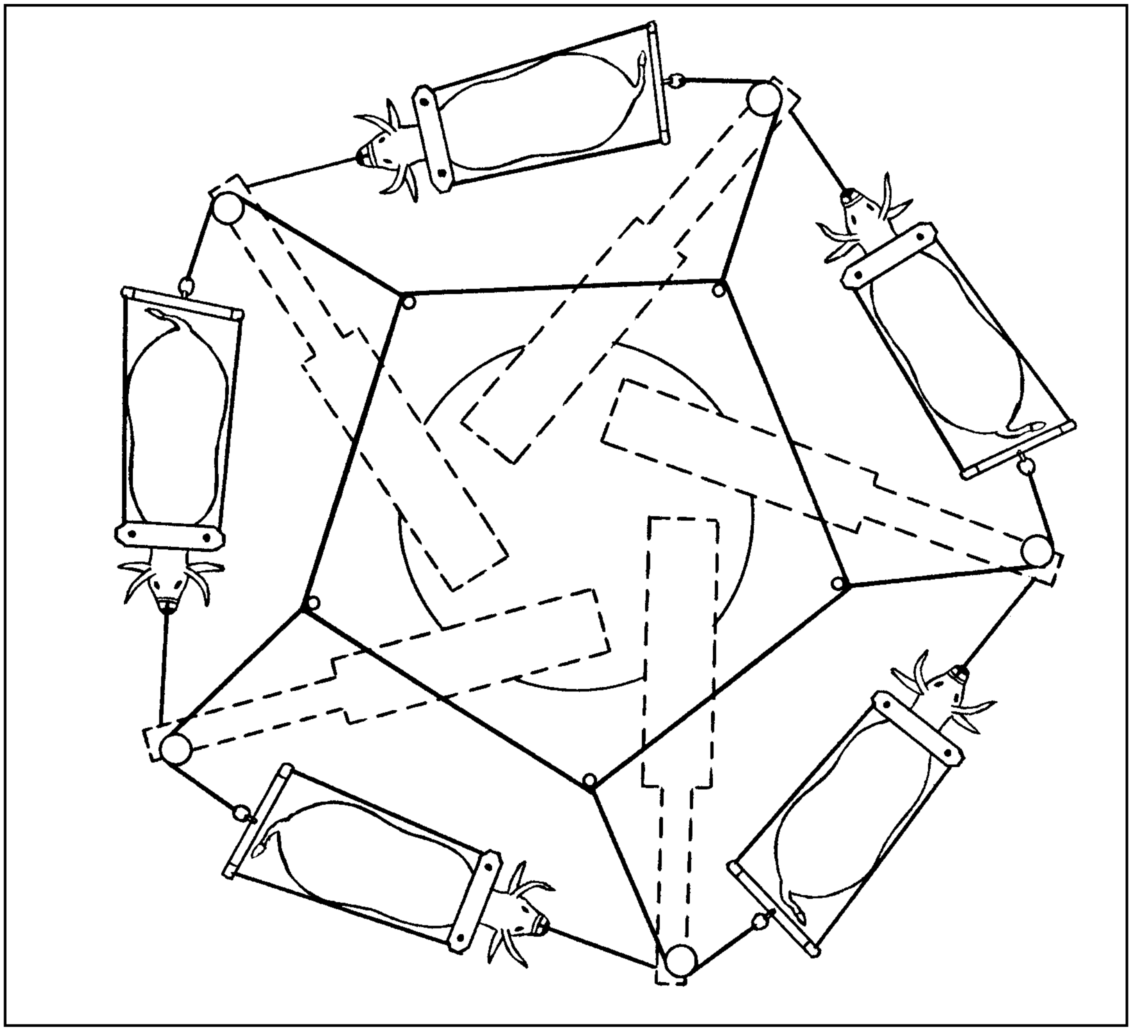
Gita-nagari's
Ox Power Unit



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INTRODUCTION

In this article we will describe how we built an ox-driven, sweep-powered generator. The concepts behind the design and operation of this unit are not new or complicated. Throughout history all over the world, man has used the same principles to produce power from draft animals. Traditionally, the mechanisms used to produce power have been made of wood, but we have constructed our generator from metal components, with the objective of maximizing the strength and efficiency of the unit. Five oxen pull the tongues which a circular motion. Then, the motion is geared up, and the direction of the rotation is changed so that we end up with a shaft spinning at 765 rpm that will provide 60 horse-power. By using various types of pulleys off the final shaft, any range of speed can be achieved to drive any type of equipment desired.

To construct a machine similar to ours, you must have access to certain raw materials and the facility to convert them for usage. The sizes and strength of the components used in this unit have been carefully engineered and coordinated, so that any reduction of the given specifications will undoubtedly result in failure. In our case, many of the parts we used were not new, but we made it a point to be sure that used components were of good quality. Precision is essential. At one point, we ran into a lot of trouble with a used 2 3/16” shaft that was 4’ long, but 1/10000” out of round.

Much of the work involved can be done with basic metal working tools, but there is also a lot of work that must be done by skilled machinist. We did most of the work ourselves with an oxy-acetelyne torch, electric arc-welder, drill press, and similar tools. In addition you must have access to a metal lathe. We were lucky to have a neighbor who does this work as a second job, so we avoided paying the inflated prices of a specialty metal-working machine shop. What follows is a section-by-section description of how the unit is constructed.

THE DIFFERENTIAL

The heart of the power unit is the differential, which is the rear end of a large truck. This unit must be carefully selected and converted to be able to withstand the torque which will be acting on it. Therefore, it is important to have a basic understanding of the manufacturer’s power rating. A tractor trailer’s differential strength is given in the number of pounds of overload it can withstand. The largest differential that we could find was rated at 23,000 lbs and came from an International 215 truck. It is essential that truck have only one rear-end, not two (twin screw), and the axle must be at least 1 3/4” in diameter. These two factors are crucial.

The differential must be in good condition, otherwise problems will arise from there being too much play in the parts. Initially we to a differential from a truck which had been caught in a flood and we were able to get it for a very good price. Unfortunately, however, some water hade got in, and the gears were slightly rusted and pitted, so we had to discard it and get another one.

It is possible that you will find a differential with two speeds. This would be a nice feature for the power unit. The ratios R-speed, rear-end, are 7.66 to 1, and 5.5 to 1. It is essential that at least one axle is kept with the differential, and preferably the second one should be kept also, as they have been known to “twist” if not installed perfectly. In fact, at this point, it is very convenient to obtain the entire length of the drive shaft, including both sets of universal joints.

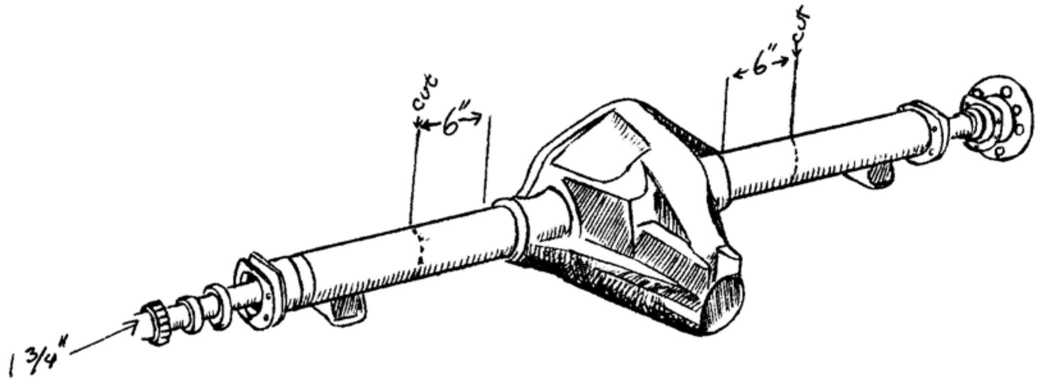


Fig. 1 Truck differential and axles. Pull axles out, then cut approximately 6" from housing on both sides.

The cheapest way to get all these parts together is to find a truck that has been junked for reasons other than having a faulty differential. If you locate one, simply pull both axles and disconnect the drive-shaft. Now you can torch the housing on both sides so that you don’t need to carry away both wheels and axle housing, which are very heavy. Make the cuts six inches or so on each side of the pumpkin (Fig. 1), and this will be plenty to work with.

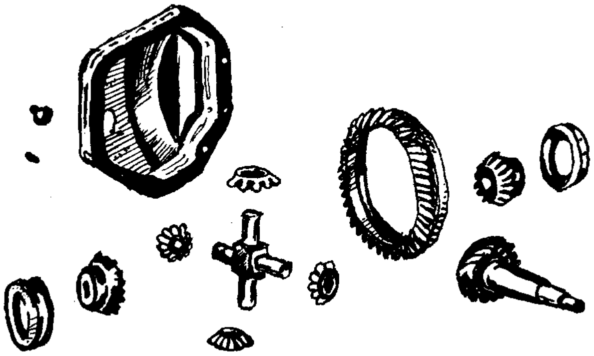


Fig. 2 Exploded view of differential, showing four pinion ("spider") gears.

Now you must convert the differential so that it can be turned on its side. Doing this will ultimately transform the horizontal circular motion of the oxen to a vertical turning of the final take-off shaft.

Working on the differential and its housing will require the help of a professional mechanic who has specialized tools and knows manufactures’ specifications. The pumpkin, which is the inside the working of the gears, should be pulled from the housing. After it is out, you can begin to disassemble it until you get to the core of the unit, where the four pinion (“spider”) gears are located (Fig. 2). These are the gears that normally allow one axle to power the truck while the other axle spins freely, for example, when driving around a curve.

Since we want the top axle to spin constantly and turn the drive shaft, we must invalidate the function of these gears. They can be either welded in place or offset into the space between where they normally sit. This will be easily understood by a good mechanic and is a common practice on race cars. Now is also a good time to replace gaskets that are worn. It is most important that is pumpkin be reassembled professionally, as all bolts have specialized torque requirements, and all gears that mesh have precise “backlash” tolerances. While the pumpkin is out of the housing, it is a good time to measure how far in the axle has to be placed so that its end splines match up with the splines of the differential.

Also, while the differential is out of its housing, this is the time to work on the housing itself. As stated before, the differential will be turned on its side in the frame. The housing should be cut now, very close to where the working gears will lie when the pumpkin is installed. This cut should be extremely square so that a ½” plate can be welded to cover each end and provide plenty of room for bolting the differential into the frame (Fig. 3). The dimensions of our plate were 11” by 18”. These plates must be welded on so that they are precisely parallel to each other. And, most importantly, they must be exactly perpendicular to the axle, as it will come out of the top of the differential.

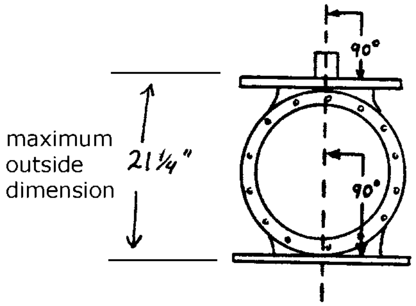


Fig. 3 Cut must be exactly square. Plates must be welded to pumpkin so that they are precisely parallel to each other and exactly perpendicular to axle.

Once the plates are welded on, there must be no more than 21 1/4” from the outside of the one to the outside of the other. This is the height of the differential, as it will sit in the frame on its side. If for some reason, this is not possible on your unit, then the height of the frame and jack shaft will have to be increased– more about this later. You must cut a hole in the top plate to allow the axle to pass up through the plate from the differential. Now, after the differential is properly reassembled, it can be reinstalled into the housing.

The axle is now ready to be inserted into the differential through the hole in the top plate. Line up the splines together inside the differential and straighten the axle so that it is perpendicular to the top plate from all angles. Now you will need a heavy-duty flange block with roller bearings to fit over the axle and bolt into the top plate (Fig. 4). We used a Link-belt FB22428H flange block. A similarly rated make would be acceptable, as long as the height dimension does not differ greatly. Our axle was slightly larger than 1 3/4" in diameter, so we had it machined to 1 3/4" from the top down, flush to the top plate. If your axle is big enough too accommodate a larger diameter flange block, that's good, but it must be machined to within a few thousandths of an inch to fit snugly into your flange block bearing.

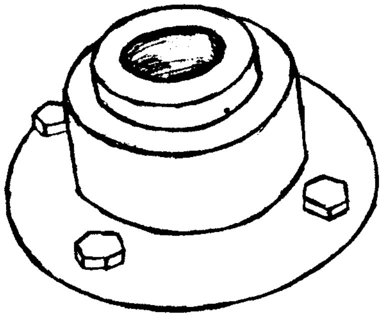


Fig. 4 Flange block with roller bearings to fit over axle. Example shown: Link belt FB22428H flange block.

After the axle is installed into the differential and held in place by your flange block bearing, you can prepare to mount the sprocket that will eventually drive the unit (Fig. 5).

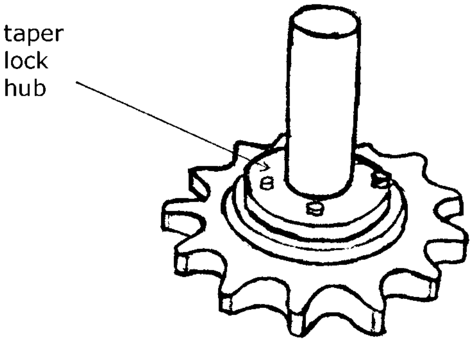


Fig. 5 Sprocket must run from #140 chain, having a minium of 12 teeth. Sprocket should be fitted with taper lock hub.

The sprocket must run from a #140 chain and have a minimum of 12 teeth. The sprocket should be fitted with a taper-lock hub to provide maximum tightening on the axle. This kind of hub uses a key to hold it against the shaft, so a keyway must be cut into the shaft at the right height above the bearing. Normally, a 1 3/4" shaft would warrant a 3/8" key. This would require a 3/16" by 3/8" keyway in the axle. However because this would weaken the shaft at this vital point, we used a shallow key-way of 1/8” by 3/8” in the axle. At this time, you may mount the sprocket on the axle (Fig. 6). Then cut the axle off at least 6” above the top of the sprocket, to allow for another flange-block to be mounted above at a later point.

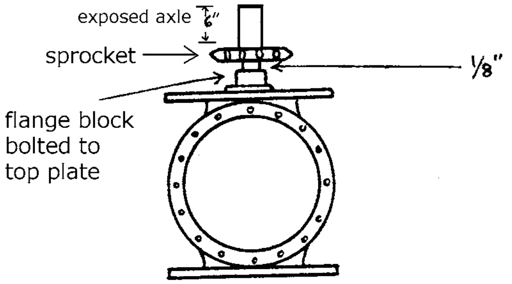
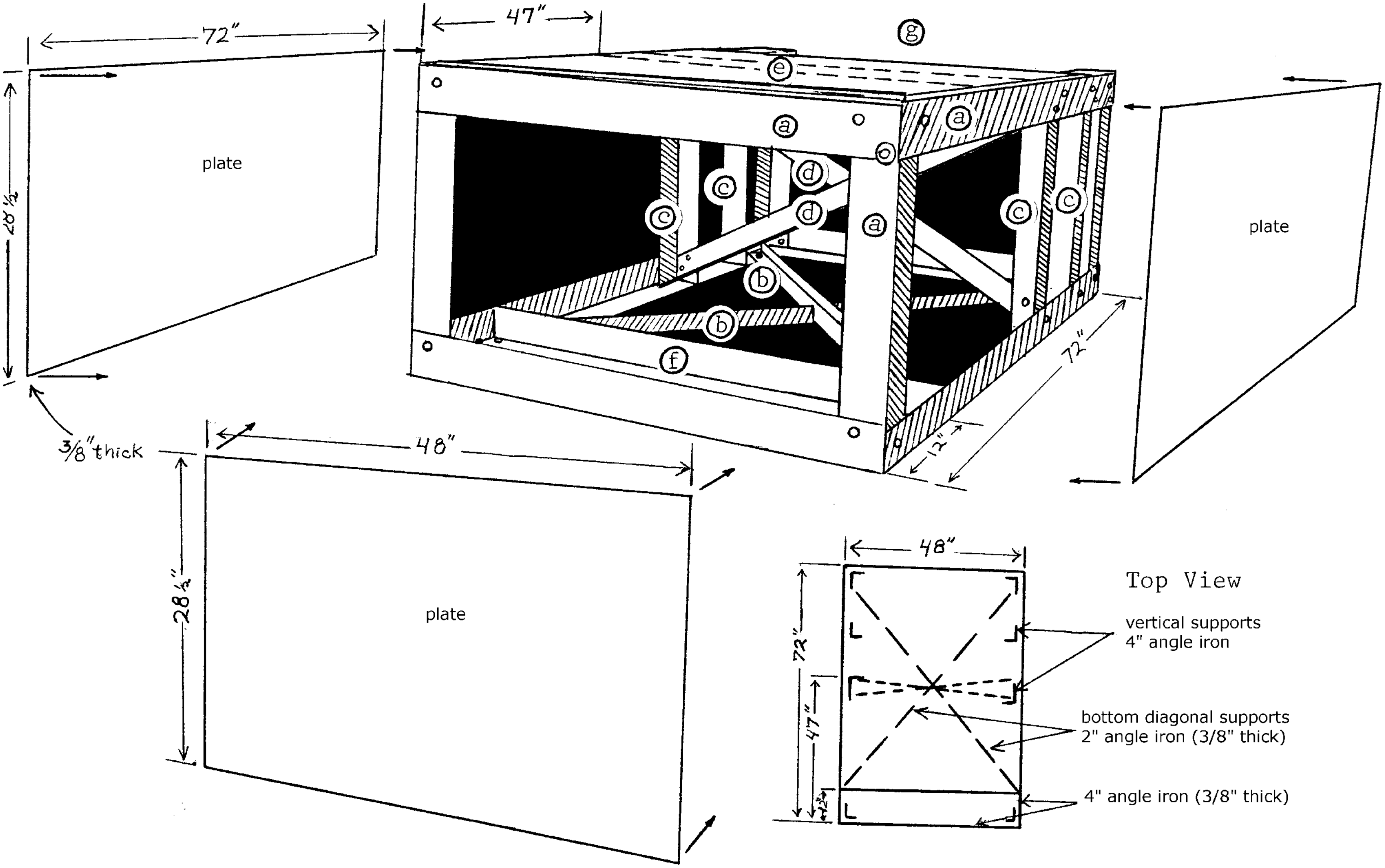


Fig. 6   Shows sprocket, bearing, axle.


72"
47"
plate
28 ½"
3/8" thick
48"
28 ½"
plate
plate
72"
12"
a
a
a
a
b
b
c
c
c
c
d
d
e
f
g
Top View
48"
72"
47"
12"
vertical supports
4" angle iron
bottom diagonal supports
2" angle iron (3/8" thick)
4" angle iron (3/8" thick)

THE FRAME

The overall external dimensions of the main frame (Fig. 7) are 72” by 48” and 28 ½” high. Special note should be taken as to how the angle iron will overlap in the corners to that these exterior dimensions are obtained. The angle iron used is 4” by 4” by 3/8”. It is essential that the frame be precisely square, so that all the gears mounted in the frame are parallel. This can be accomplished in each rectangle by making sure that both diagonals measure exactly the same.

The diagonal supports on the bottom of the frame use angle iron which is 2” by 2” by 3/8” (7b). There must be two vertical supports (7c) of 4” by 4” by 3/8” angle iron mounted on each side at a distance of 47” from the front. Again, diagonal supports (7d) are used at this same point made from 2” angle iron, also positioned 47” (outside dimension) from the front. Another 4” angle iron (7e) is mounted across the top of the frame also 47” form the front. One other 4” angle iron brace is mounted on the bottom of the frame, 12” (OD) back from the front (7f).

Fig. 7 (opposite) The frame. Take special care to allow for angle iron overlap in corners: final exterior dimensions must be exactly 72" x 48" x 28 ½" high. It is essential that the frame be precisely square, so that mounted gears will be parallel. Check by measuring the diagonals.

a. Main frame (72" x 48" x 28 ½") using (four of each length) 4" angle iron.

b. Bottom diagonal supports using 2" angle iron.

c. Vertical supports 28 1/2" using 4" angle iron.

d. Vertical cross braces using 2" angle iron.

e. Top brace – 47" from frame front, and 47 1/4" long, using 4" angle iron.

f. Bottom brace 47 ½" using 4" angle iron, 12" from front.

g. Two ½" bolts are used to fasten each overlap of angle iron.

At each overlap of the angle iron, two ½” bolts are used to fasten it securely. We found that the easiest way to build the frame was to tack-weld it together first. After tack-welding the frame together, three 3/8” metal plates for the frame must be constructed. These pieces should be cut out and tack-welded lightly to the frame. We made a portable drill press that could be clamped onto the frame at any point to drill the ½” holes. After drilling the holes through all the plates and angle iron junctions, remove the plates so that the inner workings can be installed. The differential can now be secured to the frame in exactly the spot shown in the diagrams (Fig. 8). Each corner of the differential's bottom plate is secured with a 3/4" bolt going into the frame's 4" angle iron.

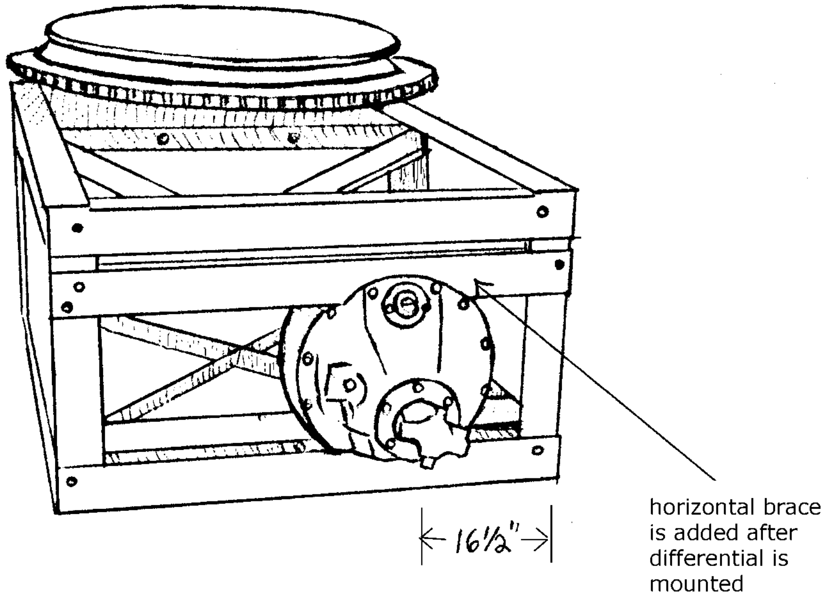


Fig. 8 Differential installed at front of frame. Each corner of differential's bottom plate is secured with 3/4 bolt into frame.

CHOOSING THE SPROCKETS

The master sprocket (Fig. 9) we used is from a large, 8 cubic yard capacity cement mixer. This is located on the front side of the mixer cylinder, and is turned by a #160 chain. To remove it, it can be torched off the cylinder body a few inches around the circumference of the sprocket. The large bearing on which it turns must also be acquired. It is very important that this bearing be in good shape. We also got some of the other sprockets required from this type of cement mixer.

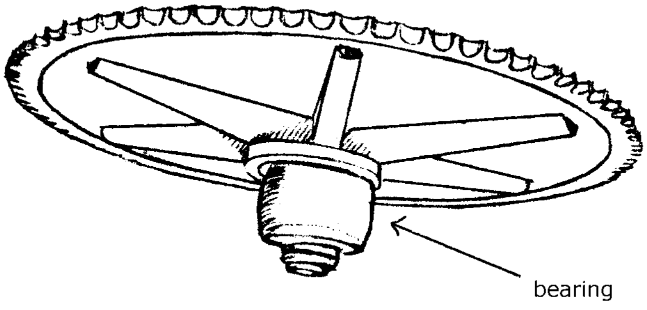


Fig. 9 Master sprocket. Ours is from a large, 8 cubic yard capacity cement mixer. Torch off cylinder a few inches around sprocket. The large bearing on which it turns must also be acquired. Our sprocket was 54", approximately 85 teeth, turned by a #160 chain.

A total of six sprockets are needed to drive the differential (Fig. 10). The top three sprockets: drive, driven, and idler sprockets use a #160 chain, while the second three sprockets use a #140 chain. These sprockets must not be excessively worn, or they will shorten the life of the chains. The chains may also be used from these cement mixers. But they must be in good shape, not "stressed out," or they will ruin the sprockets.

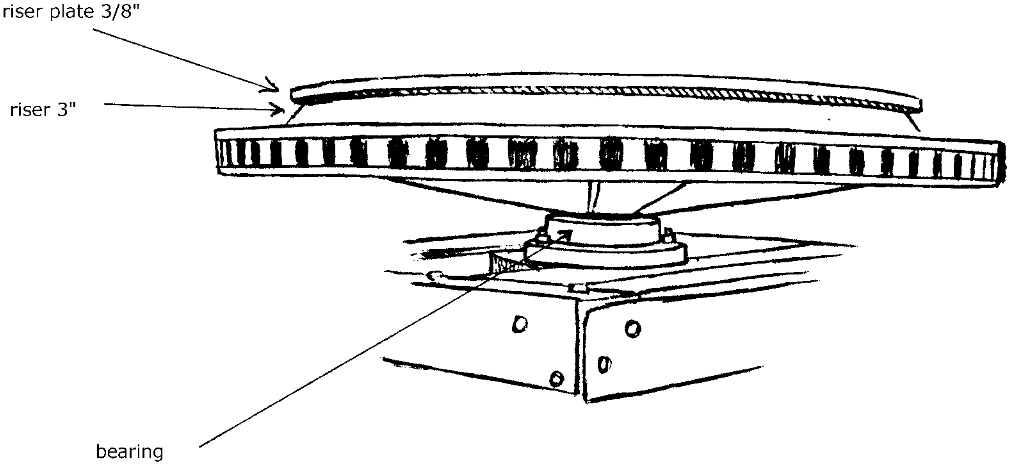


Fig. 10 Detail of master sprocket, showing riser and riser plate.

The diameters and ratios of your sprockets may vary slightly from ours. We would recommend a larger main sprocket than ours, 85 teeth would be a good size. But the crucial factor to remember is that the RPM of the final driven sprocket on top of the differential must be at least as great as ours. This will decrease the torque which is being applied to the differential and make its job a lot easier to perform.

To arrive at the final RPM, we begin by calculating for each set of gears the ratio of the number of teeth on the drive sprocket to the number of teeth on the driven sprocket. Next, multiply the two gear combination ratios together. For example, in our case, the ratios are 4.11 and 3.46, which gives us a total speed of 14.22 RPM for every RPM of the oxen walking a complete circle. We have found that our oxen will walk a complete circle 2 times per minute, which, when multiplied by the 14.22 RPM gear rotation figure, gives us a final speed on the differential axle of approximately 28.5 rotations per minuet.

MASTER SPROCKET

The large master sprocket must be installed first (Fig. 9). The bearing-housing which came with the sprocket should bolt into the far side of the angle iron which is on top of the frame, 47" from the front of the unit (Fig. 7e). We had to add a second angle iron to the frame on the other side of the bearing to give it full support. Your bearing housing may be different from ours; nevertheless, it should still have its center at 54" from the sprockets should be at least 4 ½" above the top plate.

On top of this sprocket, the poles, which we call "tongues," will be situated for the oxen to turn. To accomplish this, we took a piece of 3" channel iron and bent it into a circle, so that it would sit nicely on top of the master sprocket's metal shell. This is called a "riser" and serves the purpose of giving a platform on which to mount the tongues that is enough above the chain to prevent interference. On top of this riser, we bolted a 3/8" piece of metal and then bolted the riser into the sprocket's metal shell (Fig. 10). Now it is ready to attach the tongues, but this will be done at a later point.

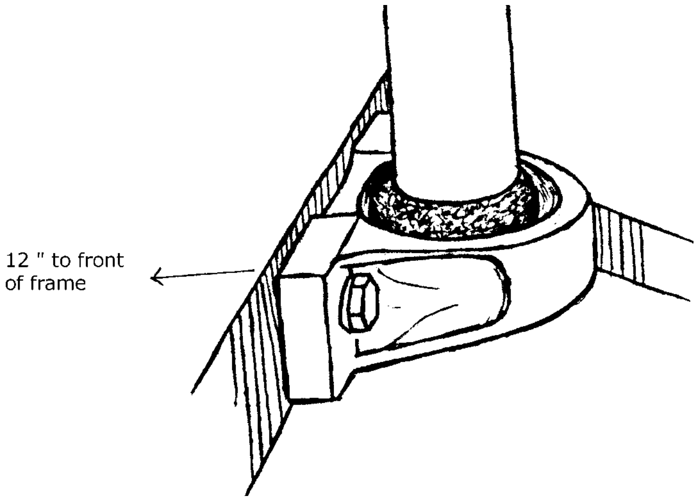


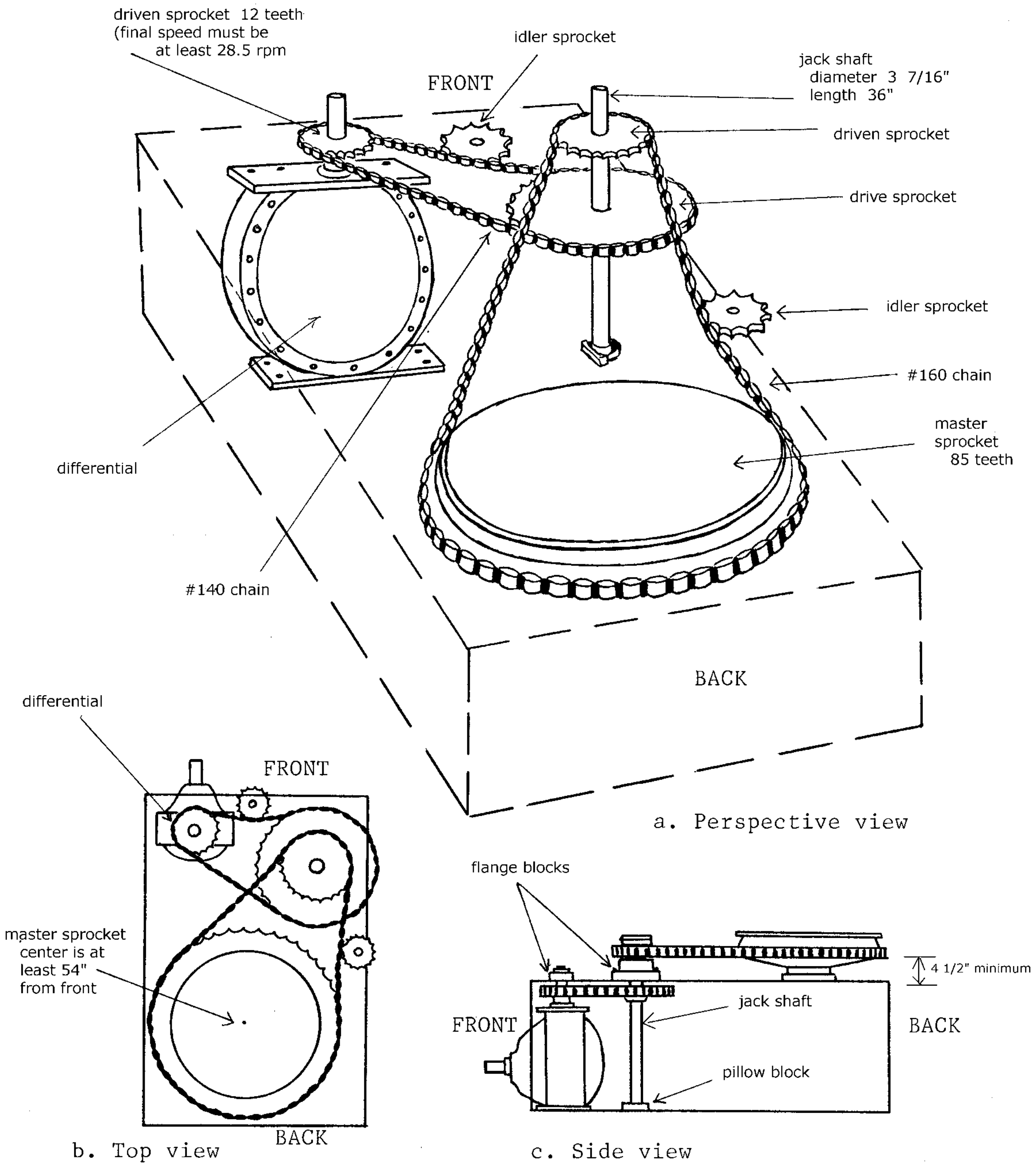
Fig. 12 Jack shaft is fixed into pillow block which is bolted to back side of bottom angle iron. Cut 4" hole in top plate directly above this to allow shaft to extend above plate.

THE JACK SHAFT

The jack shaft is the vertical shaft which is turned by the large master chain, which in turn drive the differential axle by using a #140 chain underneath (Fig. 11a). The diameter of this shaft is 3 7/16", and it should be 36" long. The bottom of the shaft is fixed into a pillow-block, which is bolted into the angle iron running along the bottom, parallel with the front, 12" back (Fig. 12, 7f). A 4" hole is cut in the top plate at the appropriate point for this shaft to extend through.

The exact positions where the two sprockets will be mounted on the jack shaft must be determined at this point, so that key-ways can be cut into it. The sprockets should have taper- lock hubs for a 3 7/16" shaft. Again, these are the best hubs to use because they have bolts that draw the hub down into the sprocket, making an incredibly tight fit around the key.

The top key-way in the shaft for the driven #160 sprocket should be at the point where the sprocket will sit exactly parallel with the master sprocket (Fig. 11c). The bottom sprocket made for a #140 chain should have its key-way cut so that the sprocket fits directly parallel with the #140 sprocket on the differential axle (Fig. 11c). We found it was a lot cheaper to cut one key-way from the top of the jack shaft down to the bottom of where the #140 sprocket sits, and



a. Perspective view

b. Top view

c. Side view

Fig. 12 Jack shaft is fixed into pillow block which is bolted to back side of bottom angle iron. Cut 4" hole in top plate directly above this to allow shaft to extend above plate.

this did not weaken the shaft. After the key-ways are cut, and the shaft is sitting in its vertical position in the pillow block (Fig. 11c), you should mount the #140 sprocket. Make sure it is exactly in line with its mate on the differential and properly torqued to the manufacturer's specifications. Now the top place can be installed over the jack shaft and the axle coming from the differential and bolted down into the frame.

The shaft is now secured at the top by using a flange block. This should be another heavy-duty flange block with roller bearings and comparable to the one we used, which was a Link-belt FB22455H. The flange block bolts into the top plate of the frame after making sure that the shaft is precisely parallel to the top of the frame and perpendicular to the other sprockets. Above this flange block, the #160 sprocket is mounted so that it is in line with the large master sprocket which will turn it. Remember, the closer the sprocket is to the flange block, the stronger it will be, but leave 1/8" separation, at least.

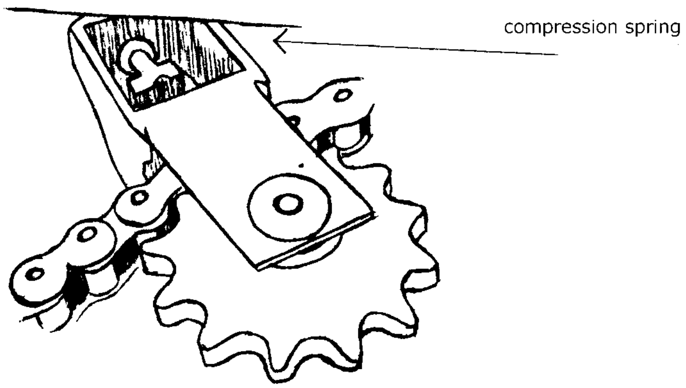


Fig. 13 Idler sprocket keeps chain tight and insures that 1/3 of teeth are engaged on every sprocket. Note compression spring.

IDLER SPROCKET

Now that the four main sprockets are installed and ready to be used, it is time that the idler sprockets (Fig. 13) be installed. These sprockets will keep the chain tight and make sure that the chain engages one-third of the teeth on every sprocket– this is minimum requirement for extended chain and sprocket life. It must be possible to move and adjust the idler sprockets for correct tension, as the chain will gradually stretch out. A great deal of tension is required to hold these chains tight. We designed a simple mechanism using very strong compression springs to pull the idler sprocket into the chain. However, another simple method of tension regulation would be to use a turn-buckle type unit. This would serve the same purpose.

After adding the top plate and installing the idler gears, we added another flange block bearing on top of the differential axle and bolted it down to the top plate (Fig. 14). This step will "sandwich" the driven sprocket on the differential axle between two flange blocks and increase the life-span of the differential,

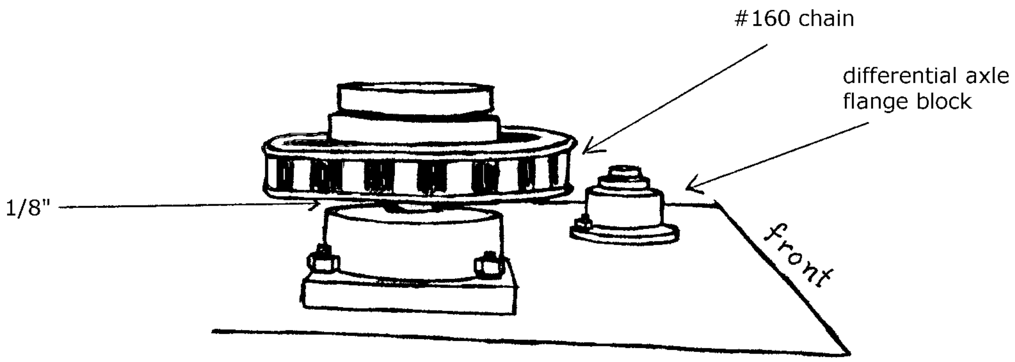


Fig. 14 Heavy-duty flange block with roller bearings mounted over jack shaft and bolted into frame.

which is most important. Finally, the side and front plates should be mounted after cutting out any sections for sprockets of the differential protruding from the frame (Fig. 15).

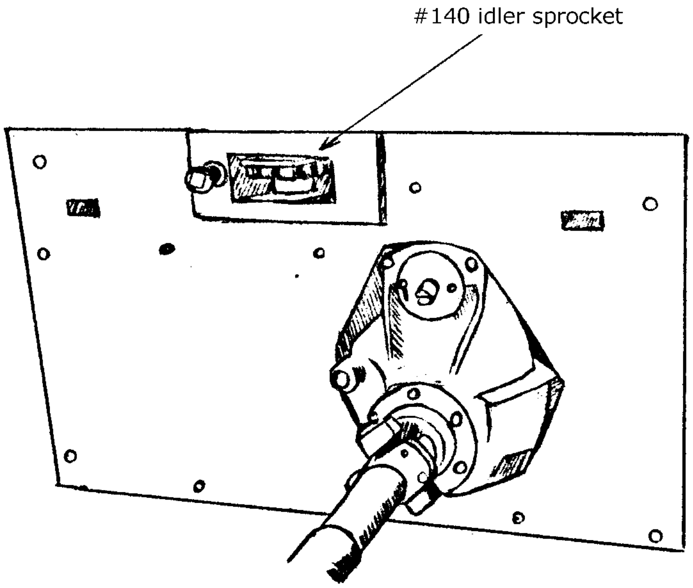


Fig. 15 Mounted front plate. Before mounting, cut away sections to allow differential and sprockets to protrude, where necessary.

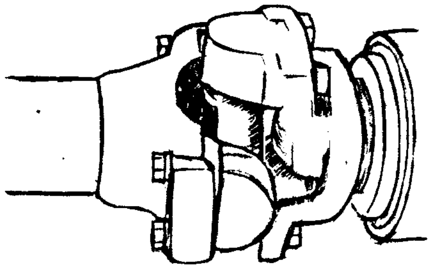


Fig. 16 Universal joint of tumbling shaft. Corresponding yokes of all three joints are lined up so they turn together.

TUMBLING SHAFT

Now is the time to get the drive shaft and universal joints form the truck. The drive shaft coming from the differential should be 4 ½' long. You may have to change yours, but it's easy. It connects at the end with a universal joint (Fig. 16). The other end also has a universal joint. On the other side of this universal joint, the tumbling shaft is connected by splined (Fig. 17). The shaft is 2 3/16" in diameter and 8' long. The outer end of this shaft must also be splined, so that it connects into the third universal joint. These U-joints must be timed just right, which means that the corresponding yokes of all three joints are lined up so they turn together. We also used a homemade wooden support for the shaft just on the far side of the U-joint. This keeps the shaft as low to the ground as possible.

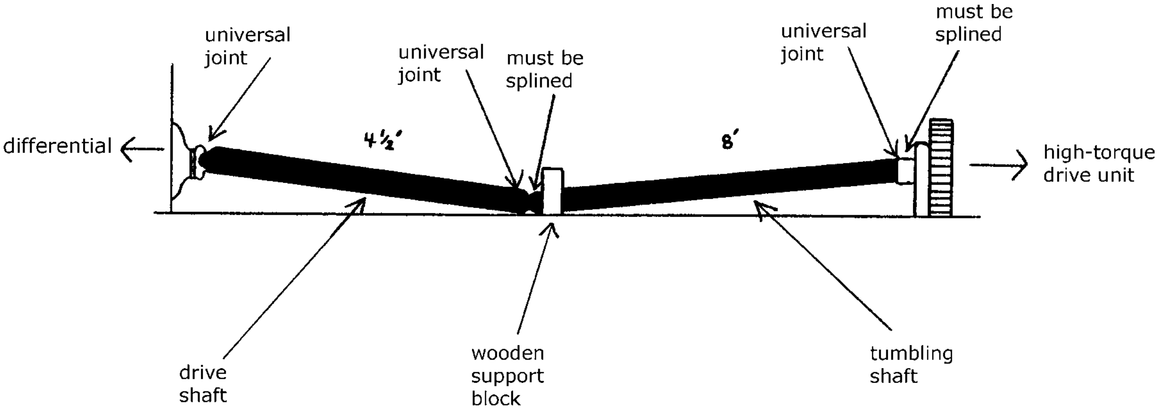


Fig. 17 Tumbling shaft.

The tumbling shaft is now spinning at around 200 RPM's and is outside the circle of oxen. Here is geared up again 3 ½" times to get a final shaft speed of about 700 RPM's. This final shaft has a large, hand-operated clutch to engage or disengage the final power take-off. The first priority for making this section of the power unit is to locate one of these clutches and also the main sprockets that you will use. The frame can be designed around the main components. We can describe our measurements and components and also share some experience.

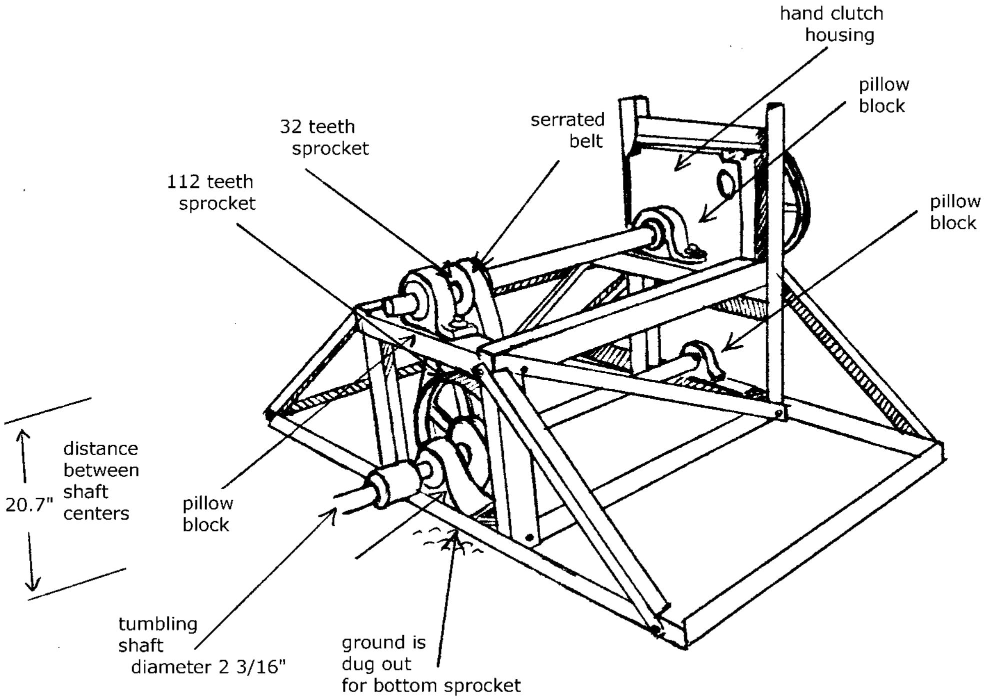


Fig. 18 High-torque drive unit. T.B. Wood's HTD unit, shown here, uses serrated belt drive instead of chain.

HIGH TORQUE DRIVE

Instead of using chain-driven sprockets here, we used a serrated belt-drive. The belt set- up has high mechanical efficiency, high resistance to wear, never needs lubrication, and runs very quietly. It needs no extra sprocket to keep it tight, as long as the center distances between the shafts is accurate. We selected T.B. Wood's High Torque Drive unit (Fig. 18). To gear it up 3 ½ times, we used a bottom sprocket, having 112 teeth, and a top support having 32 teeth. The belt is 55 mm wide and 2,100 mm long. It requires a center distance of 20.17" between the shafts.

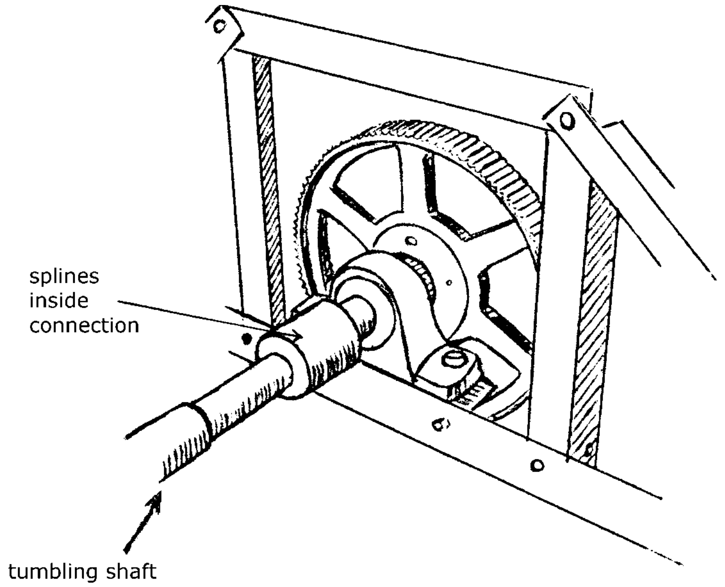


Fig. 19 HTD drive sprocket. Bottom shaft is splined and extends outside the frame to hook into the tumbling shaft.

SHAFTS

We mounted these sprockets on 2 3/16" diameter shafts. This size was convenient for us, but the bottom shaft could be as small as 1 15/16" and the top one as small as 1 3/4" in diameter. The bottom shaft is held by two pillow blocks, with one end splined and extending outside the frame to hook into the tumbling shaft (Fig. 19). The top shaft also mounts through two pillow blocks, with its far ending connecting into the fly wheel of the hand clutch. The shaft will need key-ways to hold the sprockets. The larger bottom sprocket will extend below ground level, and a protective guard should be built around it. Then the ground can be dug out, so the whole frame sits flat on the ground, with the sprocket protected below the surface.

THE CLUTCH

There are many companies which make large clutches that are operated by a hand lever. Used ones are found on a variety of power units, such as sawmills, generators or cranes. As long as the shaft coming off the clutch is at least 1 3/4" in diameter, it should withstand the load without slipping. This clutch should have a flywheel on the inside to which the top shaft on the frame can be bolted (Figs. 20,21). If you consider a used clutch, it is important to check the clutch pads and know if new pads are available. There may be only one bearing on the outer shaft and a pilot bushing on the inside. These must be in good working condition. Finally, the shaft coming out of the clutch must be keyed so that the pulleys can be fitted on without any problems.

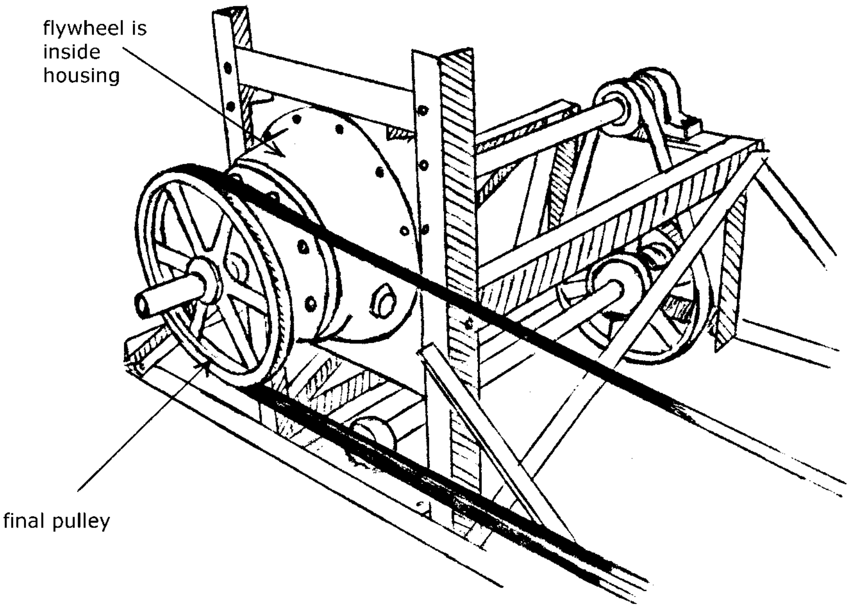


Fig. 20 Flywheel and clutch attached to HTD unit.

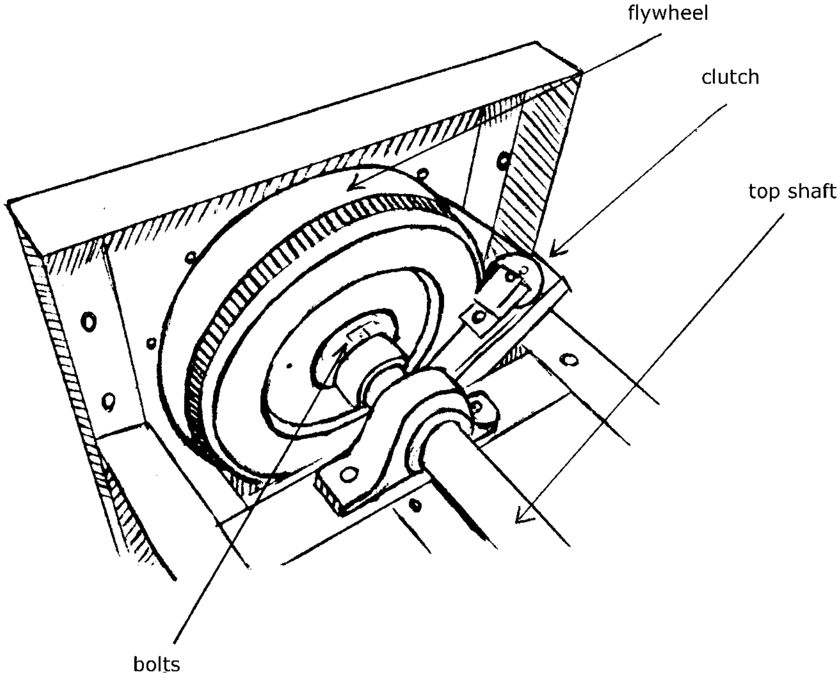


Fig. 21 HTD unit flywheel clutch. If you consider a used clutch, check clutch pads and find out whether new replacement pads are available.

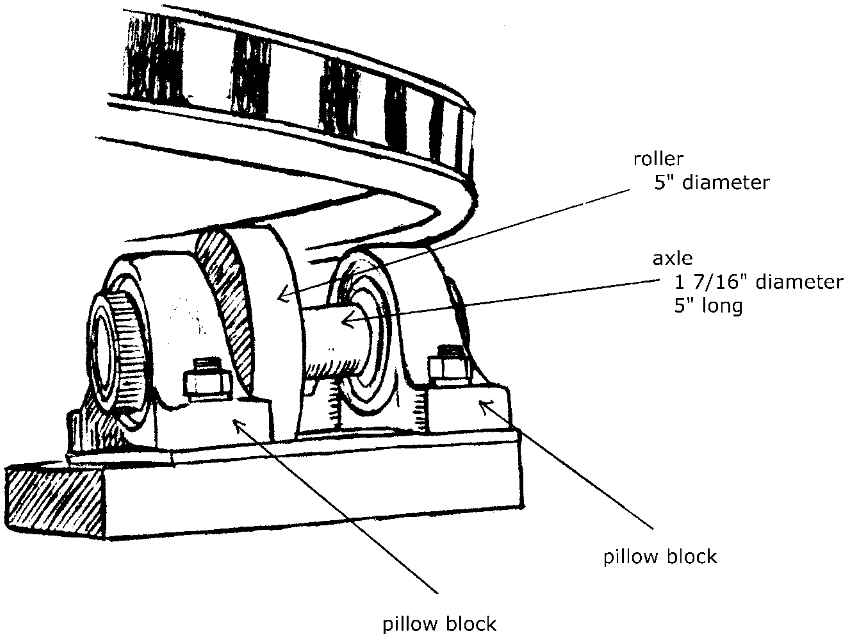


Fig. 22 Master sprocket stabilizing rollers keep master sprocket level as it rotates. Outside edge or roller must be hardened to prevent mushrooming of metal.

STABILIZING ROLLERS

These rollers are used to keep the large master sprocket level as it rotates (Fig. 22). They are place underneath the sprocket, just inside where the chain rides on the teeth. Six rollers are used in all. Three of them go side-by-side, underneath the sprocket closest to where the driven sprocket is located. The other three get spaced evenly around the sprocket (Fig. 23).

The rollers are made of 1" wide steel that is cut from 5" diameter stock. A 1 7/16" hole is bored in the center so that an axle is held at both ends by pillow blocks (Fig. 22). After the exact position of the roller on the axle is determined, they should be welded together. The outside edge of the roller must now be hardened to prevent mushrooming of the metal, which is otherwise most certain to occur.

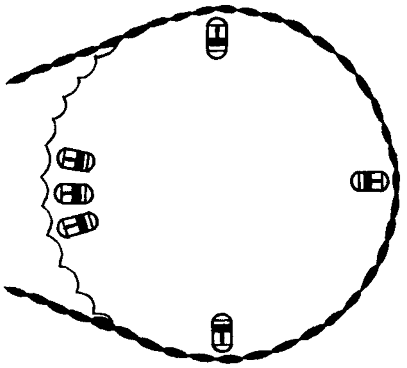


Fig. 23 Placement of stabilizing rollers beneath master sprocket.

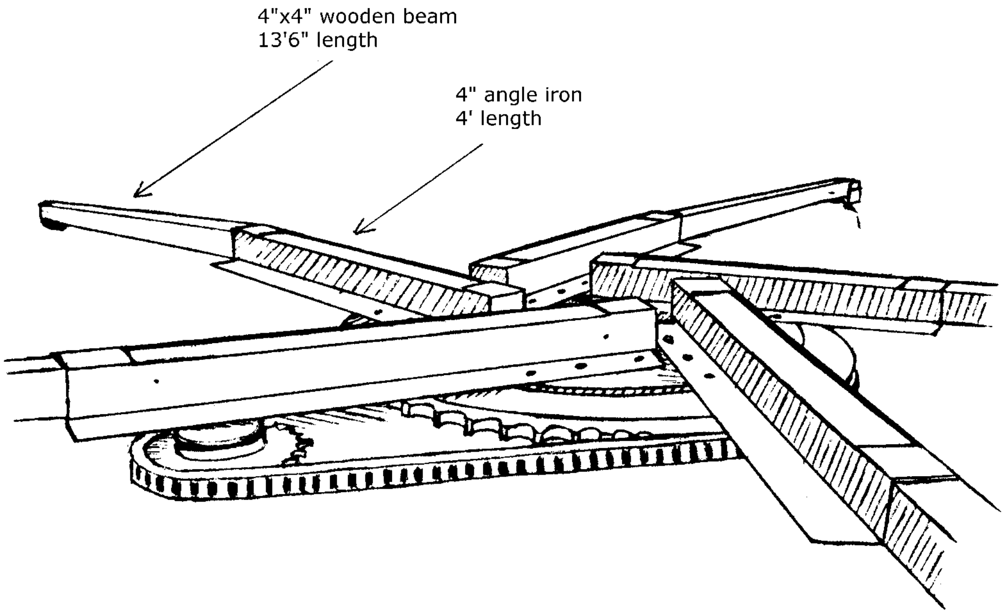


Fig. 24 Five tongues turn the master sprocket. Angle iron is attached to both sides of tongue.

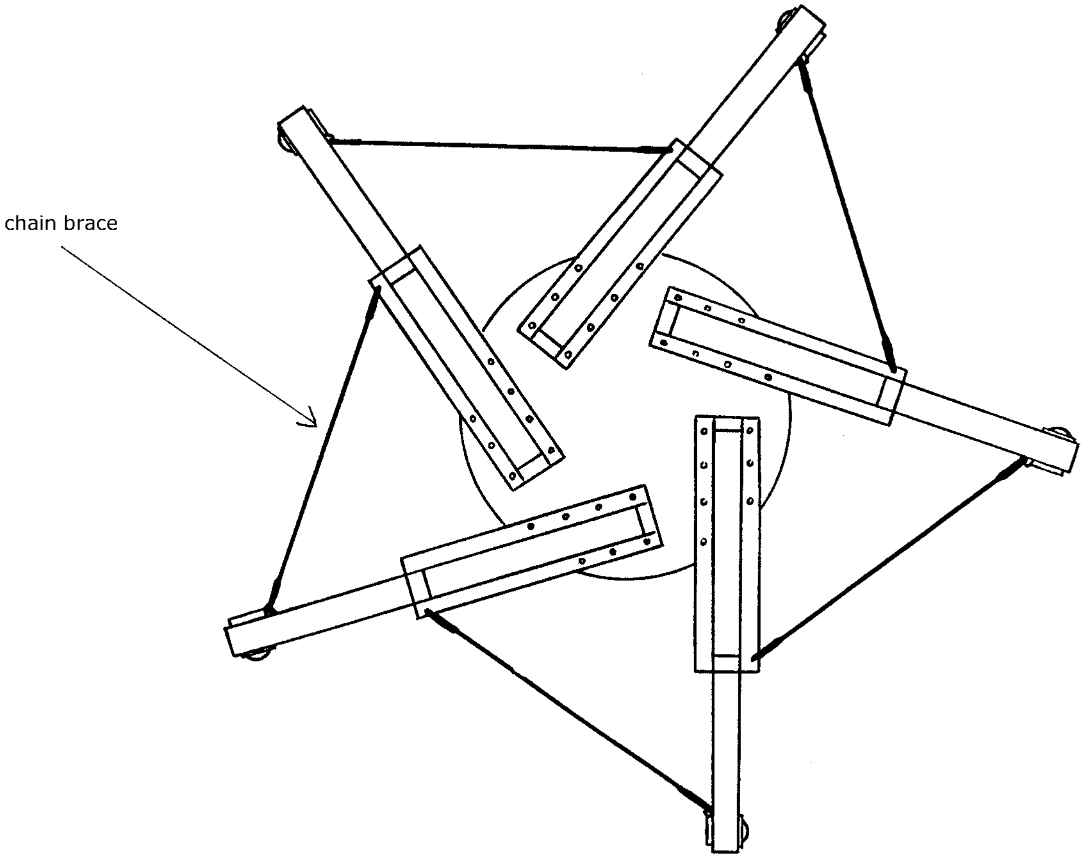


Fig. 25 Overhead view of tongue arrangement, showing chain braces.

TONGUES

There are five tongues that turn the master sprocket. The tongues are 4" by 4" wood, 13'6" long (Fig. 24). They are held by 4" angle iron that bolts into the riser plate. Angle iron is on both sides of the tongue and is 4' long. Both pieces are connected at the top and bottom for strength. To relieve most of the tension from the wood, a chain brace is used on each tongue (Fig. 25). The chain runs from the end of each tongue back to the metal angle iron on the tongue behind. A turnbuckle is used on each chain for easy adjustment (Fig. 26).

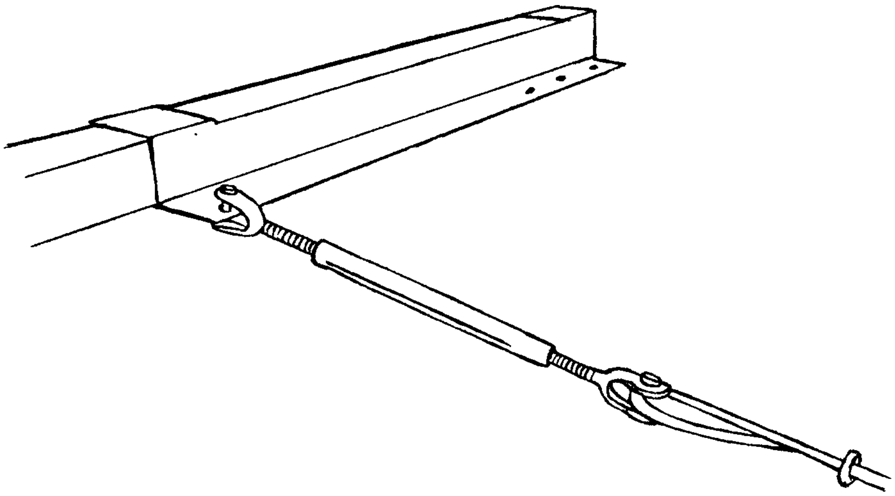


Fig. 26 Detail of Fig. 25, chain brace between tongues, showing turnbuckle for tension adjustment.

EVENERS

An evener is set-up is necessary to limit the fluctuation in pull, which would cause the unit to turn in irregular RPM's. A 5" pulley is mounted at the end of each tongue by using two pieces of 4" by 6" angle iron (Fig. 27).

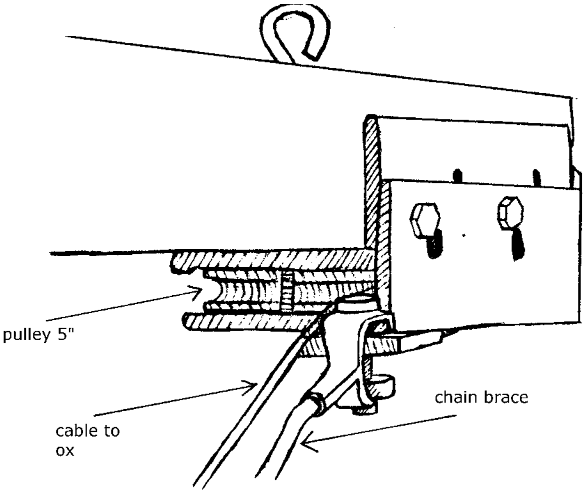


Fig. 27 Detail of evener set-up at end of tongue.

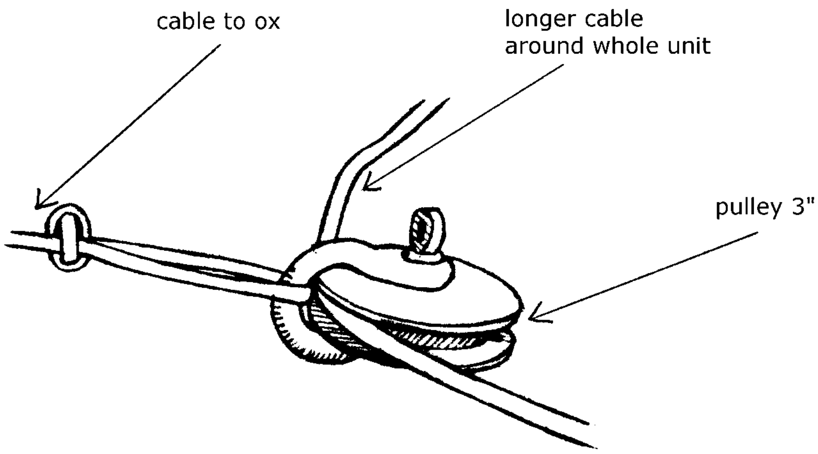


Fig. 28 Detail of evener set-up showing smaller pulley.

A cable goes from the pulling ox or oxen back around the outside of the pulley and then 270 degrees around the pulley. The cable continues on to another smaller 3" pulley attached at the end (Fig. 28).

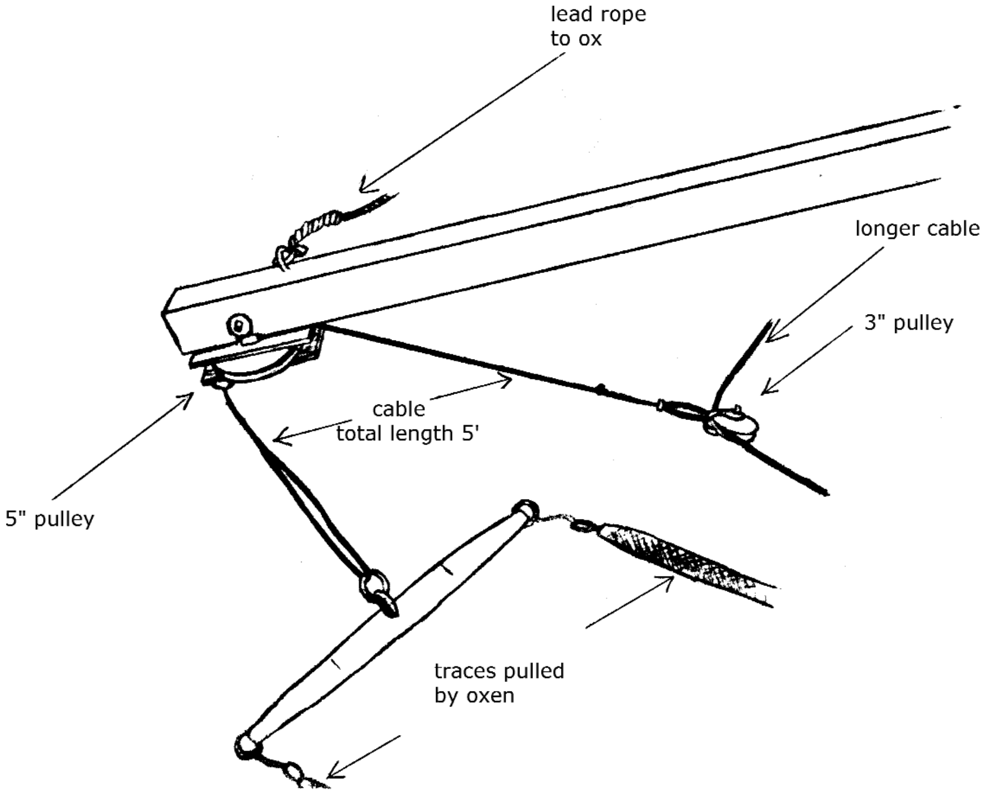


Fig. 29 Evener set-up showing complete pulley arrangement.

Total cable length is 5', with even amounts on either side of the large pulley (Fig. 29).

To connect all this together, a large cable passes through each of the five smaller pulleys and connects back to itself to form a complete circle (Fig. 30). Thus, as the oxen are pulling on their individual small cables, the pull is transferred to the large cable, and it is immediately taken up by the others.

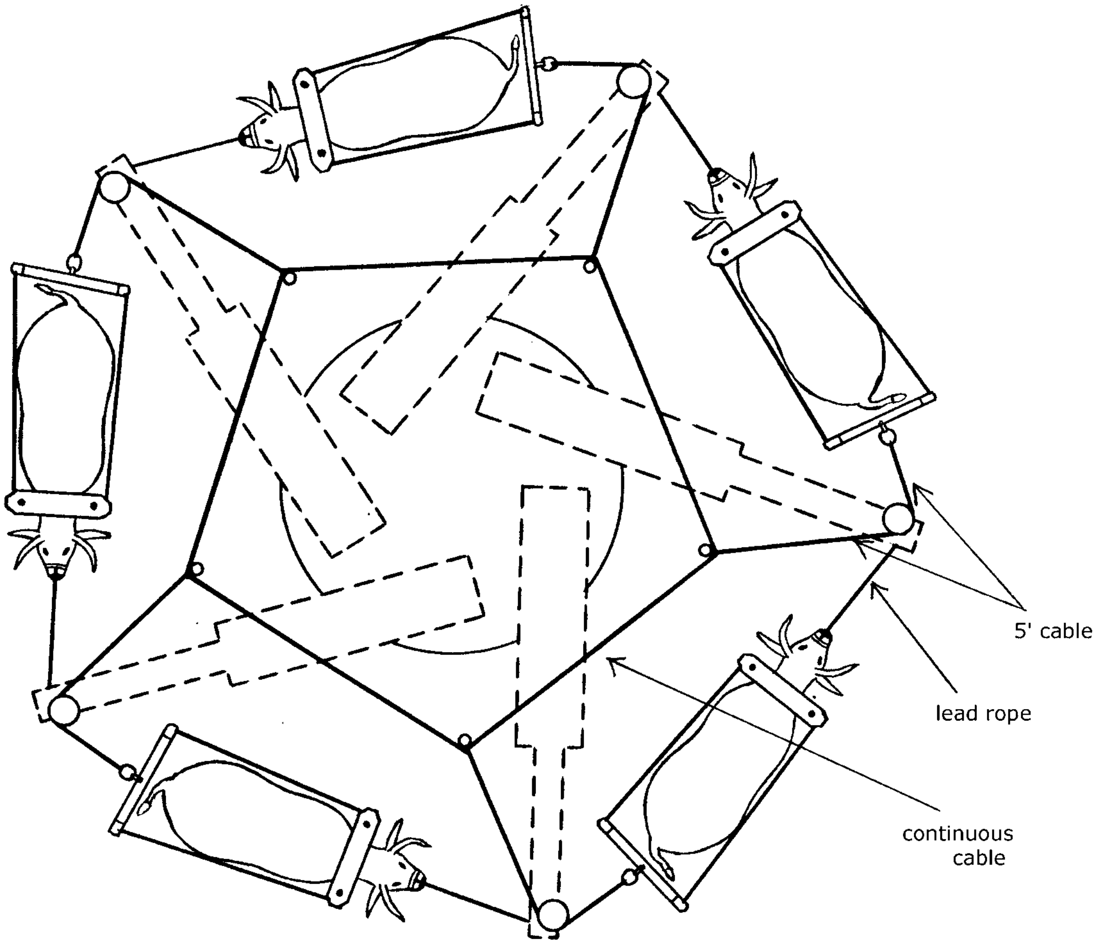
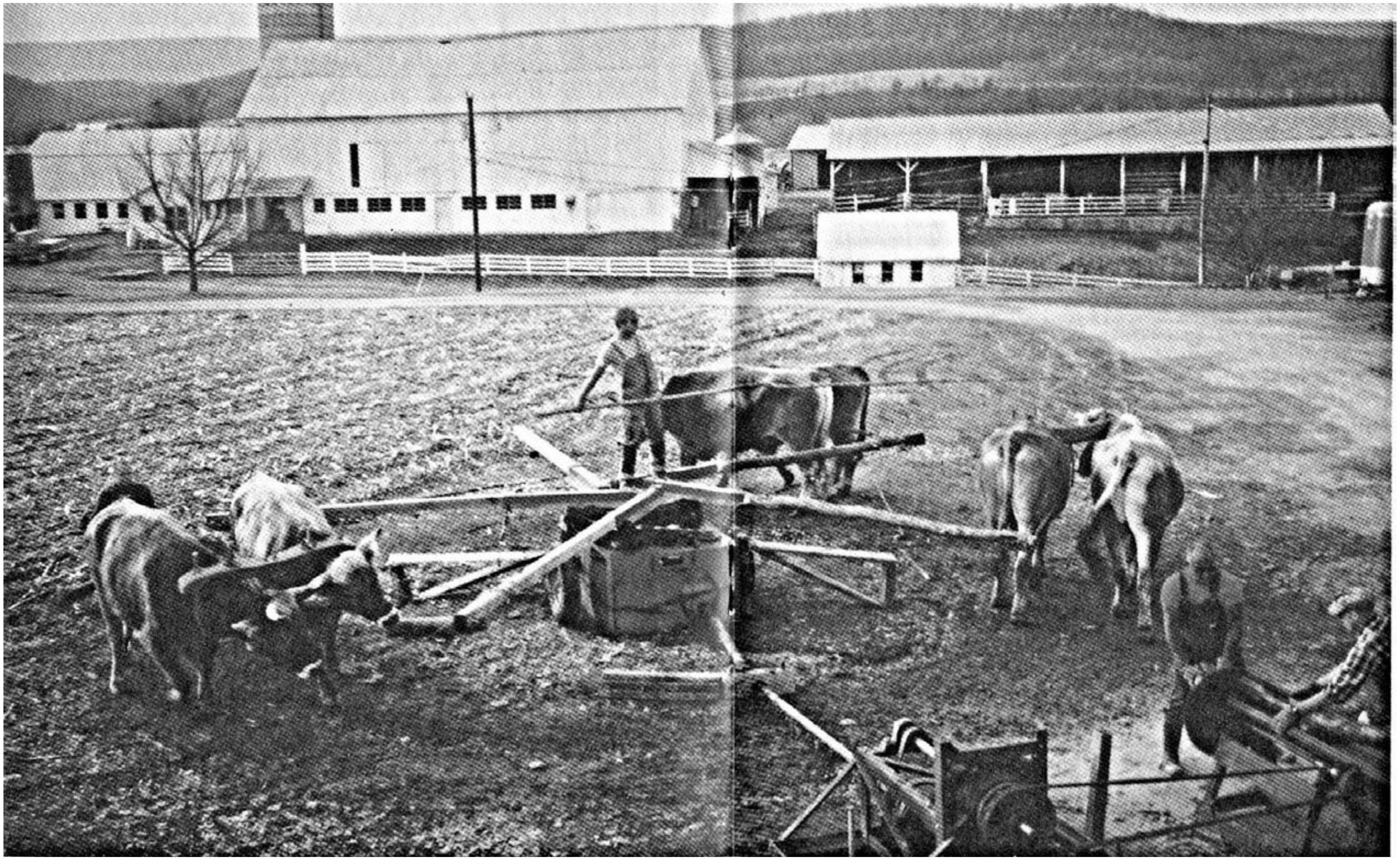


Fig. 30 Comprehensive view of pulley arrangement, showing placement in relation to master sprocket tongues and oxen.

We underestimated the importance of these eveners at first. However, after a few weeks of running our power unit, we noticed that the oxen had to walk a little to far forward to get a good pull. So we shortened the larger cable by about 18" around. Thus, each of the smaller cables got pulled by a little. The result was astounding: our oxen were able to pull much more easily and much harder with half the attention by the driver. After this, one driver was more than able to handle the whole unit single-handedly.



Gita-nagari's Ox Power Unit was built in 1985 as a project of Gita-nagari's Adopt-A-Cow program, to demonstrate the value of working oxen using improved alternative technology. For about five or six years, the oxen provided all the heating requirments for 60 residents of the farm. Residents selectively cut trees on the hillsides, and oxen pulled them down to the ox power unit, where they were sawed to the wood-stove specifications for the temple and various homes. The oxen then delivered the cord wood to each location around the community. In the early 1990's the use of the unit was abandoned as Gita-nagari shifted its focus away from self-sufficiency. But the unit, well-sheltered, can still be inspected at Gita-nagari where the community welcomes interested visitors.