turning that big array

Homebrew this inexpensive, quiet rotator

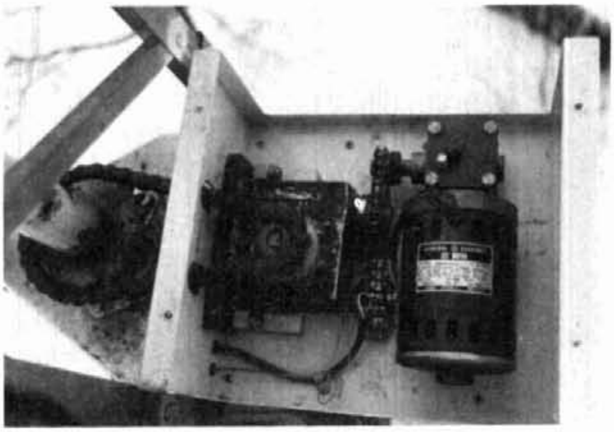

fig. 1. Worm gear reduction drive; input drive shaft is horizontal, output drive shaft is vertical.

I recently bought, and was faced with the problem of rotating, some large five-element monobanders made by a manufacturer whose promotional materials emphasize their products' ruggedness and resistance to wind damage. Until that time, my largest antenna had been a loaded 2-element beam for 40 meters that could be handled by a HAM IV rotor. But my new antennas were much more massive — for example, my booms measured 3 inches (7.6 cm) in diameter, thus presenting a wind load that was not only large, but unbalanced as well because the boom length each side on the mounting mast differs slightly. This imbalance increases the stress on any rotator in high winds. Wise heads, then, agreed that disaster would be certain unless I obtained a heavier rotator.

Unfortunately, such rotators are expensive. In the past, Amateurs used World War II surplus prop-pitch motors designed for bomber aircraft; these, however, are no longer plentiful and also come with their own set of problems. I concluded that it should be entirely possible, in a city as diverse as Toronto, to find enough surplus mechanical components to homebrew a rotator at reasonable cost. What follows is not a detailed, step-by-step construction article, but instead a description of a general approach that can be adapted to suit the materials at hand.

mechanical design

A trip to the local surplus store uncovered a 20-to-1 worm gear reduction drive and a powerful single-phase, capacitor-start induction motor with integral gear reduction. The shaft speed of the motor is 56 rpm at 50 in.-lb (5.6 N.m) torque. It draws 2.1 amperes at 115 VAC. These two parts form the heart of the rotator and should be purchased first because the rest of the design will depend on how these have to be mounted and coupled together. The type of worm drive shown in **fig. 1** is ideal, in that the input drive shaft is horizontal, and the output drive shaft is vertical; this facilitates running a chain drive to the mast. Furthermore, it mounts with four bolts at the bottom, making it easy to mount on a horizontal plate. Because a worm drive cannot be back-driven, no brake is required.

The type of motor used, common on the surplus market, is available with various speed and torque ratings. The exact rating isn't too critical, as long as the product of speed and torque is at least 1500 and the

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speed is low enough so that the rest of the drive train can reduce it to the desired antenna rotation speed.

drive motor and gearbox

A tremendous amount of torque is not required; the ruggedness of the gearbox is far more important. After all, if static friction is overcome, the antenna will eventually come up to speed, at which point its inertia will help keep it moving. Since most installations now use a high-quality ball-type mast bearing, starting would be a problem only if this bearing were iced up solid. Be that as it may, with the sprocket and gear ratios I used, and disregarding losses, the torque at the antenna mast works out to approximately 4500 in.-lb (508 N.m). (I suspect it might be possible to have a too-powerful motor that might damage the gearbox if the antenna mast were frozen.) There are formulas in machinery handbooks for calculating the size of components in the worm drive, but because these are based on a continuous running load and a certain working life, they're of little use if you want to know the ultimate yield strength under catastrophic load conditions. With carefully selected components, this type of failure would seem unlikely — and, in any case, as I'll show later, this type of failure isn't really catastrophic after all.

other components

As for the various other drive parts, suppliers sell a standard range of mechanical components, such as bearings, drives, gears, sprockets, and chains, at reasonable prices. The particulars of these components can be found in specialized catalogs (such as from Boston Gear Company, 14, Hayward Street, Boston, Massachusetts 01271), in the same way that we select standard values of electronic components from manufacturers' and distributors' catalogs. If a part isn't in stock, the supplier can almost always get it quickly through a distribution network. All the components used here except the motor and gearbox, which were bought at surplus, and the mast coupling, which was custom-machined, are standard components.

When I disassembled the gearbox, I found that its gears were also standard Boston Gear parts, so that in the unlikely event of a failure, it could also be repaired. This is one advantage of building your own rotator; because the parts are standard, reasonably priced, and readily available.

The mechanical parts required include the following:

- **Flanged cartridge.** A high-quality, sealed, ball-bearing unit set in a horizontal mounting flange (**fig. 2**), it can support both thrust and radial loads. The one I used could take about 2000 pounds (907 kg), although it's only a small unit and takes a 1-1/8 inch shaft (2.85 cm). Mounted at the bottom of the mast, it takes the full weight of the antenna array through the machined adapter shown in **figs. 2** and **3.** My unit's mounting holes were very close to the standard rotator mounting bolt pattern, so only a bit of

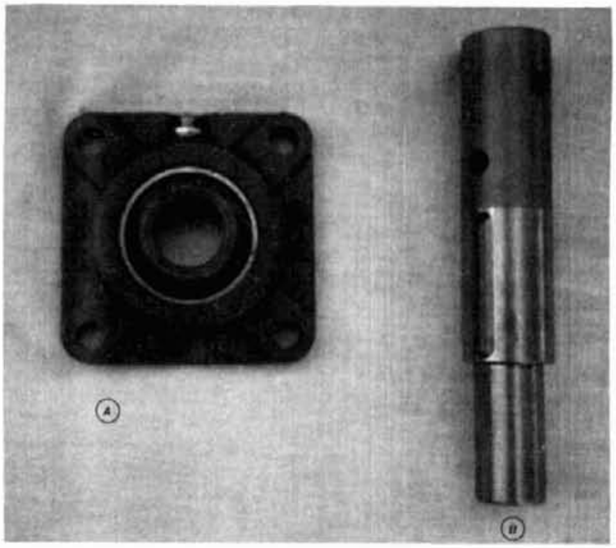


fig. 2. (A) Flanged cartridge is a high-quality ball-bearing unit set in a horizontal mounting flange. (B) Hollow steel pin secures mast adapter to the mast.

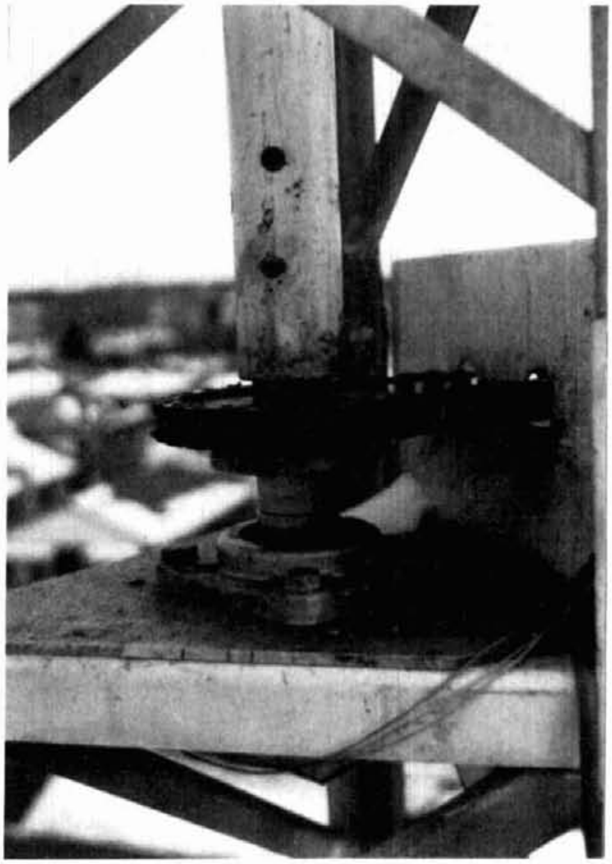


fig. 3. Completed mast assembly consists of chain drive steel pin and flanged cartridge.

filing was necessary on the tower's existing mounting holes.

- **Sprockets.** These are quite similar to bicycle sprockets. The type I used is available for various shaft sizes and is keyed for convenience in mounting and to prevent any slippage between shaft and sprocket. When the sprockets are pinned with a piece of key-stock, slippage is impossible; no clamping method can ensure this.
- **Rolled pin (or split dowel).** This is a hollow steel pin with a slot running the length of it. It holds the mast adapter (**fig. 2**) in the mast, and is driven with a sledge hammer into a hole drilled through mast and adapter. The slot allows it to compress as it's driven in, for a tight fit. There are two good reasons to use a rolled pin or split dowel rather than a bolt: one, there's absolutely no free play — and any free play in a large system is dangerous, because the antennas can slam back and forth, loosening or even shearing hardware — and two, there's no protrusion as long as the correct length is used. I used two 2-inch (5 cm) rolled pins, each measuring 3/8 inch (9.5 mm) in diameter, at right angles. One is visible in the lower hole in **fig. 3**; the hole above allows ventilation to protect the mast against condensation. The pins are available in various sizes and lengths (check the Yellow Pages under *Fasteners — Industrial*), but are probably not available at your local hardware store.
- **Gears for the direction potentiometer.** Small aluminum gears in various ratios that gear down the mast rotation to drive the direction-indicator potentiometer are available from hobby shops. Make sure both gears have the same tooth size (pitch). This is readily visible; inspect carefully.
- **Chain.** Chain is available in various sizes from the same sources as the sprockets (see above). For the final drive to the mast, I used a No. 50 chain, which also happens to be a common motorcycle chain. Note that it's much cheaper to buy this from a motorcycle parts counter than from a machinery supplier. It may also be possible to scrounge the short length actually needed from a motorcycle or bicycle repair shop.
- **Keystock.** This steel rod, square in cross section, is available in 1-foot (30.48 cm) lengths. You cut the length you need with a hacksaw. The keystock fits into a keyslot machined in the sprocket and the shaft to prevent slippage.
- **Mast adapter.** This is a straightforward piece of custom-machined steel (**fig. 2**). The end with the two transverse holes slides into the bottom of your mast and is secured with two rolled pins through mast and adapter. The length of this portion isn't too critical, though it probably shouldn't be shorter than 3 inches (7.6 cm), which is what I used, to minimize play. To determine the diameter for close fit, your machinist should measure the inside diameter of your mast, since it can vary significantly from nominal. Mine was 0.01 inch (0.5 mm) undersize, which means that if the adapter had been machined to nominal, it could not have been inserted! The sprocket fits into the middle part of the adapter, which should be long enough so you can line up this sprocket with the one on the gearbox. A keyslot should be machined to correspond to the keyslot in your sprocket. Be aware that sprockets for different shaft diameters will also use different key sizes. This portion was turned down to 1.5 inches (3.8 cm), which was the maximum shaft diameter for a keyed No. 50 sprocket with 24 teeth.

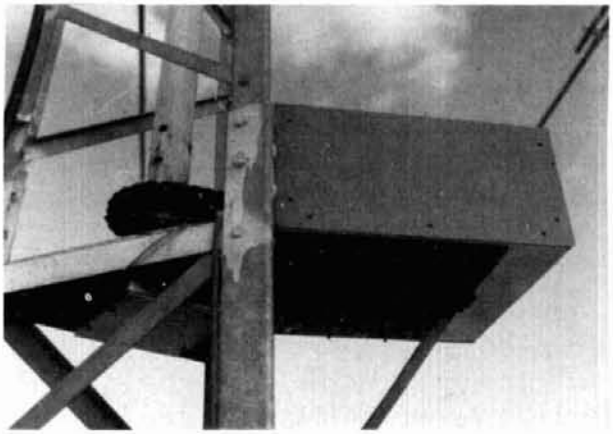


fig. 4. Bracing mounting plate to cross member prevents excessive flexing.

If you're using a large-diameter mast, I recommend machining a shoulder between the portion that slides into the mast and the portion that takes the sprocket. In this way, the shoulder takes the weight instead of the rolled pins or through-bolts.

The bottom part of the adapter, of smaller diameter, fits into the bearing in the flanged cartridge, resting on the shoulder formed by the middle part, which is of larger diameter. It should be long enough to protrude far enough below the rotor plate to mount a small gear for transmitting the motion to the direction pot. The end face was drilled and tapped in the center to take an insert onto which the gear could be mounted. Although the end could be machined down to the required 1/8 inch (3.1 mm) diameter, you would be unhappy if this little bit ever broke off. The insert is easy to machine.

The method described above for transmitting motion to the mast is superior to any mast clamping arrangement because the forces concentrated on this area are tremendous. The clamp on a popular commercial rotator has been known to loosen even in

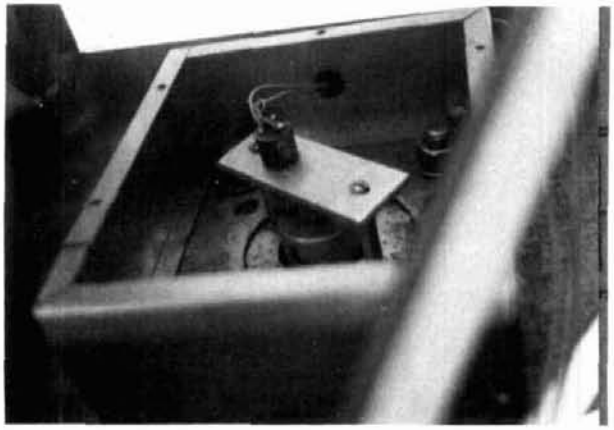


fig. 5. Rotation switch reverses output leads for reversing direction.

moderate winds, and the bolts have been known to shear altogether. A rotator manufacturer must accommodate a range of mast sizes, but you can make something that's perfect for the mast you're actually using.

As for having the machining done, any medium-size industrial town will have a number of shops that do general machining. I found one by driving through an industrial area and stopping at the first machine shop I saw; you may want to check the Yellow Pages or ask friends for their recommendations.

final assembly

When the adapter has been machined, take your mast to the shop and have the machinist drill the holes through both pieces together. This also allows you to check the fit.

My objective was a rotation speed of approximately 0.7 rpm , as a compromise between speed of rotation and starting-torque stresses on the tower. In the case of giant arrays, 0.5 rpm or less may be preferable.

The sprockets were selected this way: I wanted to use the heaviest chain to the mast for which sprockets were available that would fit both the 5/8 inch (1.58 cm) gearbox output shaft and the 1.5-inch (3.8 cm) mast adapter. The Boston Gear catalog showed that sprockets for No. 50 chain were the biggest that would allow this.

To minimize the stress on the gearbox, I wanted the maximum possible reduction between gearbox and mast. With standard keyed sprockets, this was 9 teeth to 24 teeth. A much lighter chain (No. 35) could be used between motor and gearbox. To achieve the desired rotation speed with the motor and gearbox I had, a ratio of 9 teeth to 15 teeth was used between motor and gearbox. Luckily, the 15-tooth sprocket was also the largest sprocket that could fit on the gearbox input shaft without scraping the mounting plate.

The rotor is assembled on a piece of 3/16 inch (4.76 mm) hardened aluminum plate bought from a junkyard (*also a good source of gearboxes*). *If normal aluminum is used*, I would recommend at least 1/4 inch (0.635 cm) thickness. Steel is preferable because of greater stiffness, but is much harder to work with, especially when filing or cutting, since it can't be cut on a shear. The mounting holes for the motor and gear drive must be slotted to allow the chains to be tensioned. Since the main drive chain is too heavy to tension directly by hand, a mechanical method had to be incorporated. **Fig. 1** shows the steel bar across the front face of the gearbox. Screws passing through it and the L-shaped blocks on either side of the gearbox are tightened to pull the gearbox in the direction away from the mast, thus tightening the chain. The gearbox mounting nuts and bolts are then tightened. The sprockets can be aligned by sliding them along the shafts, then securing them with the set screws. **Fig. 3** shows the mounting plate braced to a cross member across the tower face to prevent excessive flexing.

If you live in the North, make sure the grease in the gearbox doesn't solidify at low temperatures. Also, build or buy an enclosure to protect the rotator against rain. (I built another small box below the rotor plate to house the direction pot.) The mounting holes for the potentiometer bracket should be slotted to allow alignment of the gears, as shown in **fig. 4**.

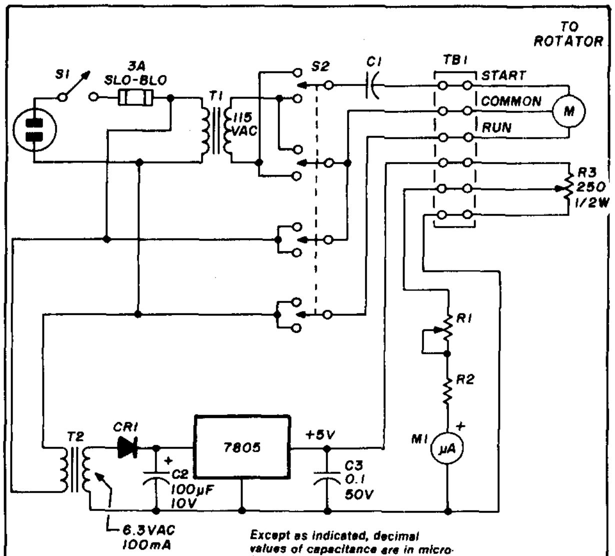
electrical design

For obvious reasons, the motor must be reversible. A capacitor-start motor can be reversed by reversing the current in the starting winding. To do this, I used a 1:1 isolation transformer in the starting winding; the rotation switch reverses the output leads for the reverse direction (**fig. 5**). The starting winding is the one with the higher resistance; the other is the running winding. Since the entire motor is rated at 2.1 amperes, I would think that a 100-watt transformer would be more than adequate. Usually only three wires are brought out from the motor, since a common return is used for both windings. If you're lucky and find a motor with the windings brought out separately, no transformer will be needed for reversing.

rotation switch and indicator pot

I didn't incorporate overtravel limit switches for a number of reasons. It was very awkward to mount microswitches and actuate them; also, many more heavy conductors would have been needed in the control cable. To minimize risk of overtravel, a spring-loaded rotation switch is used, with a center off position. Also, a meter was used for direction indication. Unlike a selsyn, this has no 0/360-degree ambiguity. If you want to use selsyns, install limit switches.

Since a pot turns only about 270 degrees, I used



Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms. k = 1,000 M = 1,000,000

C1	Motor starting capacitor. Depends on the motor. I used 10µF 330 VAC.
C2	100 µF 10-volt electrolytic.
C3	0.1 µF 50-volt ceramic disc.
CR1	1N4000
M1	Panel meter; I used a 250 µA movement.
R1, R2	Value depends on meter movement. I used 5K 10-turn trimpot and 16.2 k, 1/8-watt, 1 percent metal film resistor.
R3	250-ohm, 1/2 watt potentiometer 1/8 inch (3 mm) shaft.
S1	SPST switch, 2-ampere contacts
S2	4PDT switch spring-loaded with center off position, 2-ampere contacts.
T1	Isolation transformer; need not be more than 100 VA rating.
T2	Step-down transformer; 6.3 VAC 100mA rating.
TB1	Terminal block.

fig. 6. Control box schematic.

gears to couple to the mast. The exact gear ratio isn't critical, since full-scale deflection can be adjusted by the resistors in series with the meter (**fig. 6**). I recommended at least a ratio of 1:1.5, which provides for some travel past 0 and 360 degrees. (270 degrees × 1.5 = 405 degrees). Use a small pot with a 1/8 inch (0.318 cm) shaft, so standard Japanese gears can be used.

antenna direction

Antenna direction is displayed on a large panel meter. I painted over the original calibration, retaining only the scale, and used dry transfer lettering to re-label it in degrees. I wouldn't recommend using the original zero on the meter scale as your 0-degree azimuth point, but rather the next major scale marking. This is because a pot wiper seldom goes to 0 ohms, and you would risk damaging the pot or losing your calibration by having the pot rotate on its mounting if you accidentally went a bit past 0 degrees. I used a meter with a 250 microampere movement, but other movements (up to 1 milliampere) would be appropriate if the resistors in the control box were changed.

calibration

The direction indication can be calibrated as follows; it's best done on a sunny day. Take the control box outside for convenience. After deciding which scale markings on the meter will be your 0 and 360-degree points, turn the antenna for 0 degrees indicated. At this time the antenna heading isn't important because we're first calibrating the meter only for full-scale deflection. Place a long stick on the ground, in line with the antenna boom, or in line with the shadow of the boom. Rotate the antenna 360 degrees so the boom once again lines up with the stick. The antenna should have turned in a clockwise direction. Adjust trimpot R1 for 360 degrees indication on the meter. Double check the 0-degree point and repeat the above if necessary. Now you're ready to calibrate the true heading of the antenna.

Using one of the usual methods, rotate the antenna until it points to true North. The meter should show between 0 and 360 degrees. Loosen the mounting nut on the pot and turn the body until the meter reads 0 degrees. Your control box is now calibrated.

One of the nice features of this rotator is quiet operation. The tower doesn't resonate with the clang of a wedge brake disengaging and engaging, since no brake is provided or needed. Rotation is totally inaudible from the ground. Maintenance consists of keeping the chain greased and tight (though not *too* tight) and greasing the bearing once in a while.

I hope you have as much pleasure homebrewing and using your own rotator as I did.

ham radio