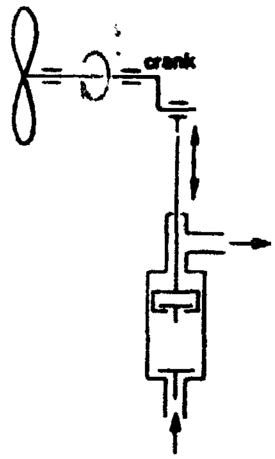
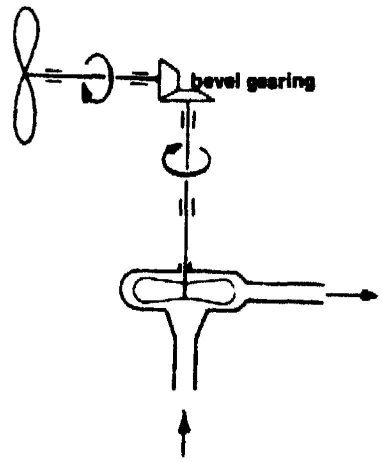
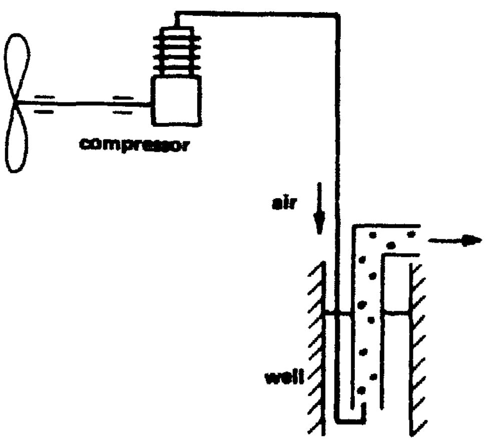


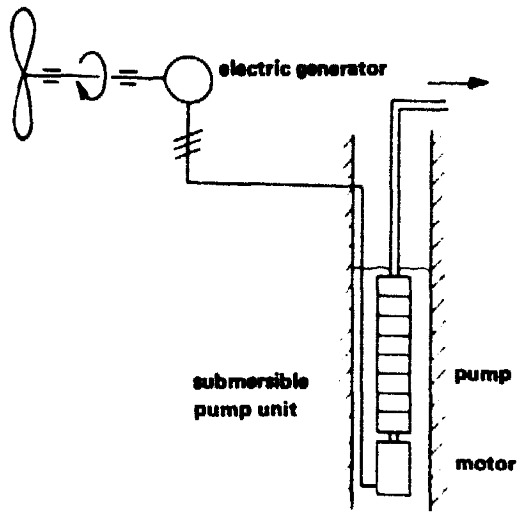
Windmill driving a piston pump:
most common type



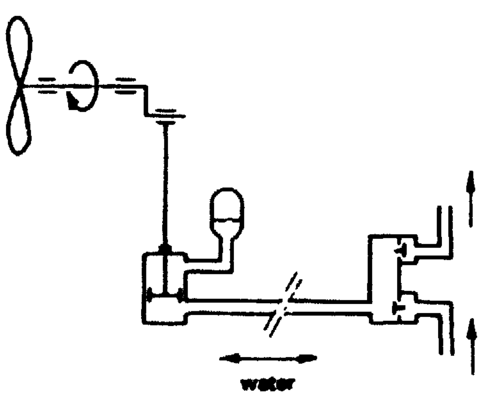
Windmill with a rotating transmission:
low head/high volume



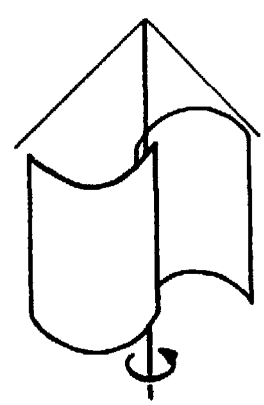
Windmill with a pneumatic transmission, driving
an air lift pump: no moving parts in the well



Wind electric pumping system:
remote pumping, large flow rates



Windmill with a hydraulic transmission:
experiments with remote pumping



Savonius rotor:
of no practical interest

Figure 2.3. Types of wind pumps classified according to type of transmission.

2.1. Types of wind pumps

A variety of wind machines are being used for water pumping. A convenient classification can be made on the basis of type of transmission between the wind rotor and the pumping device (Figure 2.3).

- **Windmills driving piston pumps.** The wind rotor is coupled mechanically (directly, or through a gear box) to the piston pump. This is by far the most common type and will be discussed in more detail in the following section.

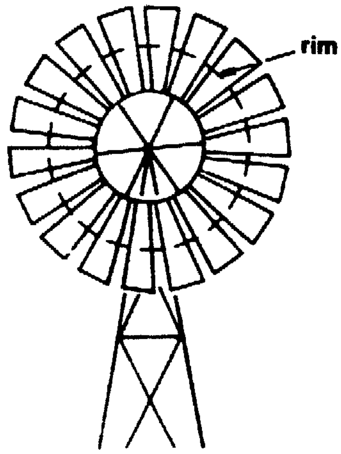
- **Windmills with rotating transmission.** The wind rotor transmits its energy through a (mechanical) rotating transmission to a rotating pump, for example a centrifugal pump or a screw pump. Both are used especially for low head/high volume applications.

- **Windmills with pneumatic transmission.** A few manufacturers fabricate windmills driving air compressors. The compressed air is used for pumping water by means of an air lift pump (basically two concentric pipes), or a positive displacement pump (basically a cylinder with a few valves). This type of transmission allows the windmill to be installed at some distance from the well. Another advantage is the absence of pump rods, and — in case of an air lift pump — of any moving part inside the well.

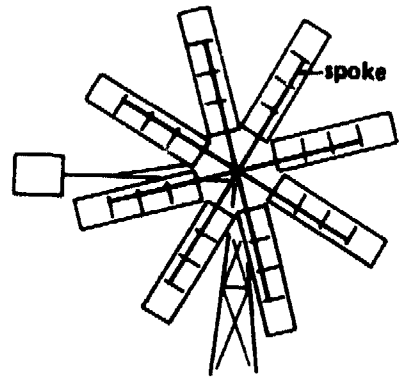
- **Wind electric pumping systems.** Wind electric generators are sometimes used to drive electric pumps directly (without being coupled to an electric grid). Again, this transmission provides the freedom to install the wind machine at a windy site at some distance from the well. Electric submersible pumps may be used to pump water from narrow boreholes, with flow rates far in excess of those attainable with piston pumps.

- **Windmills with hydraulic transmission.** Several experiments have been performed on remote pumping by means of a hydraulic transmission. Mostly water is used as the operating fluid.

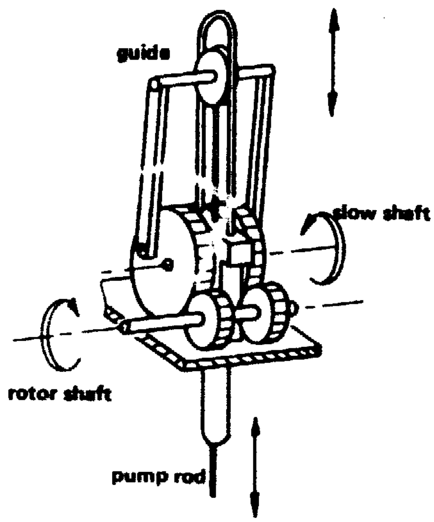
The types of windmills described above are all horizontal axis windmills. At the moment these are the only types of practical interest for water pumping. In the past quite some research effort has been put into vertical axis machines for pumping, especially Savonius rotors. However, this has not led to practical applications for two main reasons: high cost per unit of water pumped (heavy machines combined with low efficiency), and poor reliability (it is difficult or impossible to incorporate a safety system in such a design). Vertical axis Darrieus wind rotors are hardly suitable for a water pumping system, as they need an external power source for starting. Therefore, vertical axis machines will not be mentioned further in this handbook.



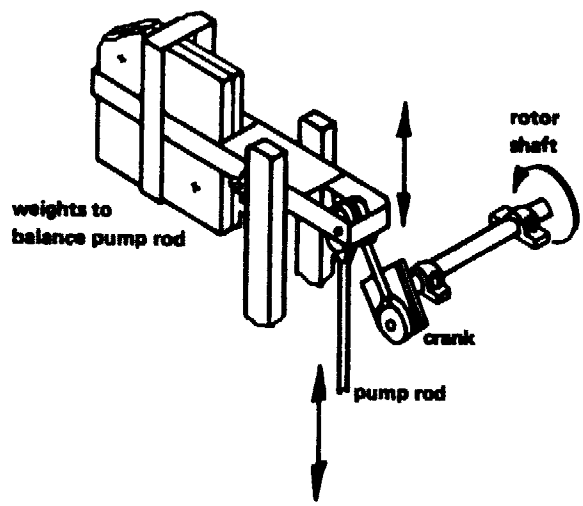
Classical multiblade rotor (heavy)



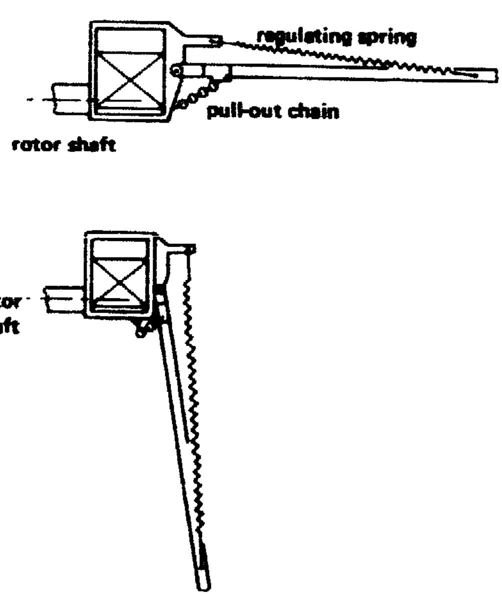
Modern rotor (light)



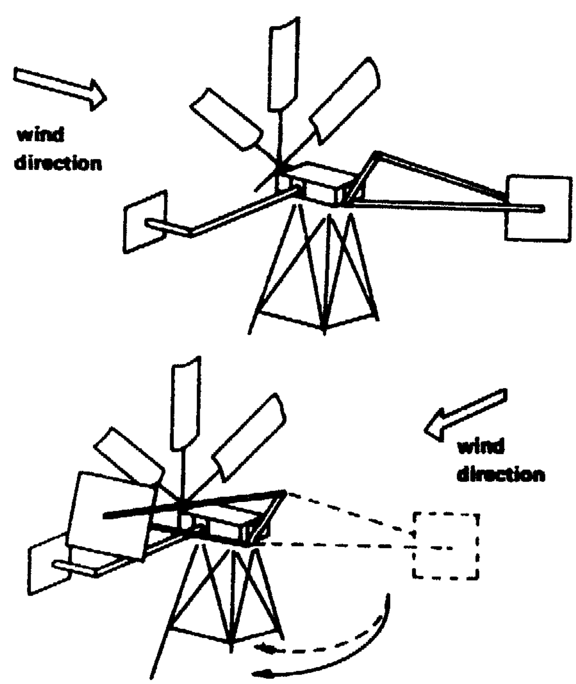
Transmission of back–geared windmill running in oil bath



Direct drive transmission



Top view of ecliptic safety system



Hinged vane safety system

Figure 2.4. Components of mechanical windmills.

2.2. Prime mover: mechanical windmill

As indicated before, the remainder of this chapter will concentrate on the most common type of wind pump: a windmill driving a piston pump through a mechanical transmission. Where appropriate, however, reference will be made to the other types. Figure 2.2 shows some photographs of such mechanical wind pumps (including one with a rotating transmission and a centrifugal pump).

In this section we will discuss the components and subsequently the characteristics of mechanical wind pumps. The piston pump, which actually lifts the water, is described in Section 2.3.

2.2.1 Windmill components

A windmill consists typically of the following components (see Figure 2.4):

- The rotor, which captures the wind's energy and converts it into mechanical energy.
- A transmission, which conveys the energy from the rotor to the pump, sometimes involving intermediate energy conversions.
- The safety system, which protects the windmill during gusts and storms.

Rotor

The rotor is the essential part of this prime mover: it converts the power of the wind into useful mechanical shaft power.

Usually the blades consist of curved steel plates. Sometimes sails are used. Classical "American" windmills have 15, 18, 24 or even 36 blades, mostly supported by a structure of spokes and rims. These rotors deliver maximum power when the speed of the blade tips approximately equals the wind speed. Recent designs have less blades: 4, 6, 8, or 12, mostly supported by spokes only. These rotors operate at higher tip speeds: For any given wind speed, maximum power is delivered when the speed of the blade tips equals 1.5 to 2 times the wind speed.

The rotor is fixed to a steel shaft by means of one or two hub plates. The shaft is supported by sleeve bearings (receiving oil from the gear oil bath), or by roller bearings (lubricated by grease or by oil), or by hardwood sleeve bearings (lubricated with oil). Rotors of water pumping windmills range from 1.5 to 8 m diameter.

In a 4 m/s wind, a rotor of 1.5 m diameter may produce up to 24 W of mechanical power, and an 8 m diameter windmill up to 680 W. In a 5 m/s wind, these values nearly double (46 and 1320 W respectively).

Transmission

The transmission of a windmill conveys the mechanical energy delivered by the rotor to the pump (rod).

Many of the classical "American" windmills, especially the smaller models are "back-geared", i.e. they incorporate a gear box. The gears reduce the r.p.m. of the pump, normally by a factor of about 3. The gears are normally double to avoid uneven loading of the crank mechanism (see below) and usually run in an oil bath for lubrication. The oil needs to be changed about once a year.

An essential part of a windmill transmission is some kind of eccentric that transforms the rotating movement of the rotor into a reciprocating movement of the pump rod. Several types exist:

- Two drive rods connected eccentrically to the two slow gears, and connected through a guide to the pump rod (see Figure 2.4).
- A simple crank on the main shaft, connected directly to the pump rod.
- A crank on the main shaft, connected through a guide to the pump rod.
- A crank on the main shaft, connected through a lever system to the pump rod (see Figure 2.4).

The pump rod transmits the power to the pump. Often a swivel joint is incorporated, pre' enting the pump rod from rotating when the windmill's head assembly is yawing due to a change of wind direction. Normally the pump rod is guided at several points in the tower. The swivel joint and the guides require regular lubrication by greasing, for example once a month. The efficiency of the transmission is somewhere between 70% and 90%.

Safety system

No wind machine can be expected to survive very long without an automatic safety system to protect it against gusts and storms. It would be impractical, even if it were possible, to design a wind machine strong enough to remain in full operation during storms, with an exception perhaps for very small wind machines of 1 m diameter or so. Hand-operated safety systems alone are not sufficiently reliable. Storms may occur very suddenly, unexpected storms may occur at night, and one moment of negligence may reduce an important investment to scrap.

The safety system of mechanical windmills is combined with the orientation system. At low wind speeds the rotor is oriented into the wind; with increasing wind speeds the rotor is gradually turned out of the wind so as to limit the speed of the pump and the forces acting on the structure.

The functioning of these safety systems is based on the equilibrium of aerodynamic forces (acting on one or two vanes and the rotor), and some other force (mostly a spring or weight) that serves to counteract the aerodynamic forces.

Normally the automatic safety system can also be operated manually to stop the windmill.