The torques acting on the stabilizing gyro due to rolling of the ship are called *passive moments*. These torques are greatest when the gyro is locked so that it cannot precess.

The gyroscopic torque opposing roll is maximum when the spin-axle of the stabilizing gyro is in the central position. When the spin-axle tilts from that position, the torque diminishes in a manner which depends upon the angle of tilt. Since only small torques are developed when the tilt is large, it is common practice to limit the precession to 60 degrees on each side of the central position. When the stabilizing gyro approaches the end of the permitted angle of precession it causes a " limit switch " to open the direct current generator shunt field. At about the same instant the control gyro also opens the same circuit. Farther precession of the stabilizing gyro drives the precession motor as a generator. Thus, kinetic energy of the stabilizing gyro is first transformed into electric energy and then into heat. This action is called *dynamic braking*. The combination of dynamic braking and the friction braking produced by the magnetic brake can bring the precessional speed to zero in less than one second of time.

The following additional braking effect is possible but is seldom used. When the control gyro releases the magnetic brake, the precession motor armature starts with high acceleration. With increase of precessional speed of the stabilizing gyro there is a decrease in the load on the precession motor. The passive moment due to the rolling of the ship increases the angular speed of the stabilizing gyro about the athwartship gudgeons. The angular speed of the stabilizing gyro about the precession axis may become so great that the precession motor acts as a generator. In case this action occurs, the direction of current in the direct current circuit reverses, thereby causing the direct current generator to operate as a motor. These actions would result in a braking effect that would diminish the velocity of precession. The opposition to the motion of precession produced by the precession motor acting as a generator is called regenerative braking.*

96. Rolling of a Ship Produced by a Gyro. — In certain cases it is desirable to be able to cause a ship to roll. For example, a

* Further information regarding the Sperry active type ship stabilizer may be found in the following U. S. Patents:

Sperry, No. 1150311, 1915; No. 1232619, 1917; No. 1452482, 1923; No. 1558514, 1925. Schein, No. 1605289, 1926; No. 1617309, 1927; No. 1655800, 1928.

ship aground may be able to free itself if it can roll toward deeper water; a ship stuck in mud may be able to free itself by rolling back and forth till the keel is sufficiently loosened; a ship may be able to break a passage through ice by rolling against the ice sheet.

A vessel equipped with a stabilizer of the active type will roll with gradually increasing amplitude if there be applied to the main gyro a periodic torque that is in opposite phase to the precession of the spin-axle that would be produced by the natural rolling of the ship in the direction in which rolling is desired (Art. 92). By changing electric connections at the switchboard, the apparatus may be caused to operate either as a reducer of rolling or as a producer of rolling.

97. Admiral Taylor's Formula. — The effect of waves on the rolling of a ship is cumulative, each wave contributing a small effect till the total angle of roll may become large. By neutralizing the small increments of roll, the angle of roll will not become large. Admiral D. W. Taylor, U. S. N., has shown that a roll increment ϕ can be neutralized by a gyro-wheel having a moment of inertia relative to its spin-axis of the value

$$K_s' = \frac{1225\,\phi D H T}{n} \tag{100}$$

where K_s' is expressed in pound-feet^2 units, ϕ is the difference in degrees between two successive amplitudes of roll in the same direction, D is the displacement of the ship in tons, H is the metacentric height in feet, T is the period of roll in seconds, and n is the spin-velocity of the gyro in revolutions per minute. The required moment of inertia may be due either to a single gyro or to two or more gyros.

The derivation of this equation never has been published, but it may be seen in the Archives of the U. S. Navy Department in Washington.

Problem. It is required to compute the principal elements of a ship stabilizer of the non-pendulous active type that will quench a roll increment $\phi = 5°$, where ϕ is the difference between two successive angles of roll in the same direction. The ship has a displacement $D = 2200$ tons, metacentric height $H = 2.5$ ft., period of roll $T = 13$ sec.

The diameter of the gyro-wheel is to be 8 ft. On account of the limit of fiber strength of steel, the peripheral speed must not exceed 33,000 ft. per min. Stops are used that limit the amplitude of precession to 60° on each side of the equilibrium position. A magnetic brake and a motor rotating at 500