of putting over the rudder be regarded as an impulse (measured by the finite product P. *dt),* delivered at the stern of the ship normal to the rudder, the resistance of the water to the rotation of the ship may be neglected, and the instantaneous centre of the turning motion (as distinguished from the motion ahead) is the point O on a straight line GB perpendicular to the direction of the impulse, and such that GO. GB = ^>an expression for the position of O of the same form as obtained before.

I'

In this case ^, = ⅛2, where *k* is the radius of gyration of the ship about a vertical axis through the centre of gravity, and the point O is obtained by the geometrical construction shown in fig. 64, given by Professor W. M. Rankine, where GL=*k* and is perpendicular to GB, and the angle BLO is a right angle.

The value of I is dependent on (1) the distribution of weight in the ship, being large when heavy weights are situated near bow and stern, (2) the length of the ship, and (3) the underwater form near the ends, being relatively large in fine ended vessels with large areas of deadwood. W is also dependent on the shape of the ship under- water.

The handiness of a ship or her readiness to respond to slight alterations in helm is mainly dependent on the relation between Q × BG the moment of rudder pressure for a given angle, and I the virtual moment of inertia. If I is comparatively large, the vessel will turn slowly under helm until, gathering way, the rapidity of its angular motion becomes so large that reverse helm may be re­quired to limit the change of course to that desired. Unhandiness is usually experienced at low speeds (Q being then small) and also in shallow water when I is increased by the restriction in the flow of water from one side of the ship to the other. Improvement in the handiness in these circumstances has been obtained in certain ships with unbalanced rudders by filling in the after deadwood, the loss from the increased inertia being more than compensated by the greater turning moment due to the pressure on the after dead- wood.

When the ship is turning steadily in a circle, if C (fig. 63) is the centre of rotation, and CO perpendicular to the middle line of ship, the motion is equivalent to a progression ahead with speed V (which is considerably less than the initial speed), combined with a rotation about the “ pivoting point ” O, which is generally situated slightly abaft the bow; the drift angle φ is given by the relation

OG=≈OC tan φ.

The time of turning through 180° is where *r* is the radius OC.

The forces acting upon the ship are now—the pressure P on rudder and deadwood (if any), the centrifugal force the

thrust of the propellers, and the pressures on the hull. The last named consist of forces P1 outwards before O, and P2 inwards abaft O; of these P1 is usually negligible in amount;. P2 cannot be directly estimated, but since work is done against it by the trans- verse motion of the after part of the ship, a reduction of speed results whose amount is largely dependent on the obliquity of motion at the centre of gravity, that is on the drift angle *φ.* Under full helm the ratio of the steady speed when turning to the initial speed is often about 60 or 70%; but in some quickly turning ships it is less than 50%. Of the remaining forces, the transverse component of the centrifugal force is known since the final

diameter of turning *2r* is approximately the same as the tactical diameter. To obtain P, it is to be observed that the water im­pinges on the rudder in a direction BF intermediate between BE (perpendicular to BC) due to the ship’s motion and BD due to the form at the stern; if BF is assumed to bisect the angle DBE, the effective rudder angle is approximately 0-φ. The pressure on the rudder is therefore less than when helm is first put over and is further reduced on account of the diminution in the speed of the ship.

From experiments made with the object of measuring P when turning steadily, it is found that the pressure recorded was about one-fourth of the value calculated on the assumption of the ship retaining her original speed and effective rudder angle; when helm had just been put hard over, from one-half to one-third of the theoretical pressure was obtained. (See *Bulletin de l'Association Technique Maritime,* 1897; *American Institution of Naval Archs. and Mar. Eng.,* 1893.) The transverse forces calculated on this basis for a battleship of 15,000 tons displacement when turning steadily under full helm are approximately—centrifugal force 200 tons, pressure on rudder 40 tons, and Q2, the transverse component of P2, 240 tons passing through a point on the middle line about 40 ft. abaft the centre of gravity.

The following equations applicable to the state of steady rotation can be obtained from the above considerations, neglecting P1 and the small couple due to R:

Qî=Q+W^s^ (i)

Q2×GM≈GB×Q (ii.)

From (i.) it is seen that a small tactical diameter will be obtained when Q2 is large compared with Q; from (ii.) it follows that the point M (fig. 63) should then be near G. These conditions are realised in a ship whose resistance to leeway is considerable but concentrated about the middle of the length, such, for example, as a yacht having a deep web keel, or a boat with centre board and drop keel. In these instances the vessel may be regarded as virtually anchored by its keel, and the pivoting point brought to a position in close proximity to the centre of gravity. Similarly tactical diameters of vessels of ordinary type are reduced by diminishing the resistance to lateral motion at the after end and by increasing it amidships or forward.

During the turning trials made with H.M.S. “ Thunderer,” observations were made of the heel caused by the transverse forces brought into play when turning. On first putting the helm over a small inward heel caused by the pressure of the rudder was observed; as the rotational speed of the ship increased this inclination was succeeded by a steady outward heel, amounting to about 1° at 7 knots speed. The latter is caused by the couple formed by the centrifugal force and the lateral resistance diminished by the (usually) small couple due to the rudder pressure. During some more recent trials carried out on the "Yashima" the angle of heel was 8¾° at full speed. Similar large inclinations are generally found with modern warships having small turning circles and high speeds and whose centres of gravity are also situated high up; at moderate speeds, however, the heel is of small amount. On putting the helm quickly amidships when turning, the opposing couple due to the rudder pressure is removed or reversed and the angle of heel momentarily increased; instances have occurred of ships with small stability and comparatively large “ rudder couples ” capsizing through this cause.

The rudders used in ships are of two types:—(1) Unbalanced, shown in figs. 65, 67, 68 ; and (2) balanced, shown in figs. 66, 67 (at bow) and 69 to 74. An unbalanced rudder is in stable equi­librium when amidships and force has to be applied to the tiller in order to place it at any angle to the middle line.

It is supported at its forward edge by means of pintles working in gudgeons on the sternpost; and owing to its simplicity of con­struction and to its property of returning quickly to the middle line when the tiller is released through any cause, this type is pre- ferred when the force required to put the rudder hard over is sufficiently moderate to enable steering to be performed by hand or by an engine and gear of moderate size when steam steering is admissible.

With high speeds and large manœuvring powers, the unbalanced type is generally unsuitable; and balanced rudders are adopted in order to reduce the force required and the work done to obtain large angles of helm. A balanced rudder is unstable amidships, and, if left free, comes to rest at a moderate angle on either side of the middle line. Slightly less than one-third of the area is usually placed before the axis; in some ships in which a greater proportion has been put forward, difficulty has been experienced in bringing back the rudder to amidships. As shown in the figures, the method of support has varied in different ships; in many cases a steadying pintle has been placed at the heel or mid-depth, but in the latest warships the support has necessarily been taken entirely inboard.

In the merchant service, unbalanced rudders of the form shown in fig. 65 are generally fitted ; the rudder extends up to, or above, the water-line, and is comparatively narrow longitudinally. Some- what greater efficiency when using small or moderate angles of helm is obtained with rudders of this shape; as, for a given pressure