

finger, and the time when the layer cannot be moved under heavy pressure. Blistering, cracking, and peeling of paint are often due to the fact that under coats were too elastic when they were painted over. If a piece of work be painted coat upon coat of oil color before each coat is sufficiently dry, the movement and shifting of the under coats in their effort to obtain oxygen for their proper hardening will either rupture—i.e., crack—the top coats or lift them up in the form of blisters. Pearce, in his excellent book on painting, says that four days is not too much to allow for the proper drying of oil color which will nominally dry in twenty-four hours. The period may be shortened by additional driers; but a good rule is to allow all paint to stand four times as long as it takes to arrive at superficial dryness.

THE ATMOSPHERIC CONDITIONS WHEN PAINTING IS DONE.

Opinions as to the best time for painting differ largely; but nearly all the standard authorities concur in the opinion that a temperature of from 55 to 80 deg. and an atmosphere that is as free from moisture as possible favor the best results.

[Concluded from SUPPLEMENT No. 1567, page 25118.]

THE DIMENSIONS OF THE MARINE STEAM TURBINE.*

THE DETERMINATION OF THE PRINCIPAL DIMENSIONS OF THE STEAM TURBINE, WITH SPECIAL REFERENCE TO MARINE WORK.

By E. M. SPEAKMAN, Associate Member.

NUMEROUS empirical coefficients for approximating steam speeds and the corresponding number of rows are obtainable from experience, and are similar in use and value to the Admiralty coefficient; that is, while they represent a crude method of doing something that should be done more scientifically, they are very simple and capable of rapid handling. Being, however, based on long and costly experiments, much reticence is observed regarding their publication. Varying, of course, with the steam pressure and vacuum, the number of rows on one diameter would involve an excessive length of turbine and also inconvenient blade heights. It is, therefore, usual to divide the rotor into three or more stages, which have the advantage of shortening the turbine and reducing the number of rows. If n = the fraction of power developed in the first cylinder or barrel, N/n = number of rows in the first barrel, and with the alteration of diameter and increase of blade velocity in the succeeding stages, the number of rows on other barrels is so altered as to keep, for equal powers and efficiencies:

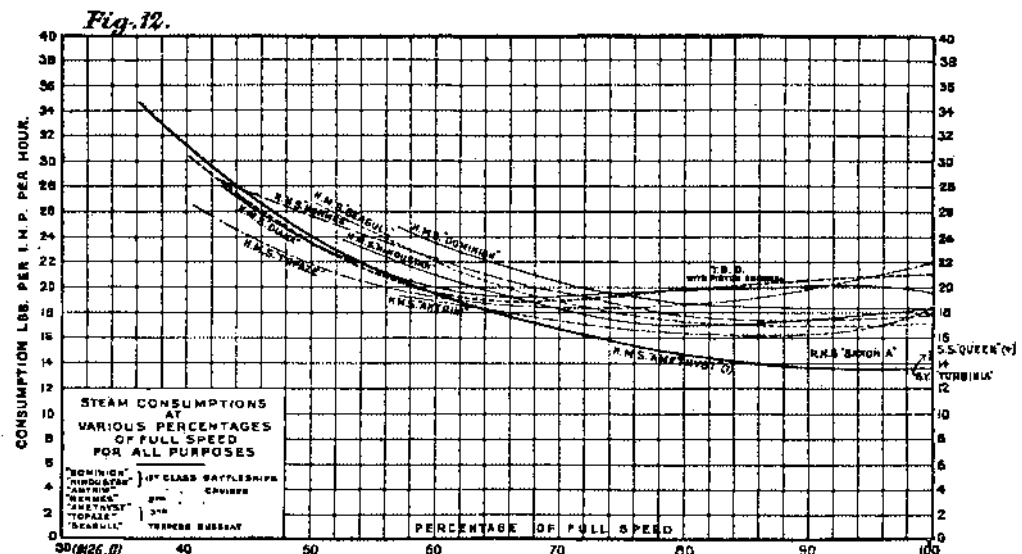
(Blade velocity)³ × Number of rows = constant.

The vane speeds adopted in practice vary considerably; for some time 100 feet per second was regarded as a standard for the first row, and I think the Westinghouse Company at Pittsburg was the first to make

be so modified that this may be at least 3 per cent of the mean diameter to reduce the proportion of clearance losses. Leakage over the tips of the blades is, perhaps, not so detrimental on account of actual leakage loss as in its superheating effect on steam between

they would be with water, and the actual forces would be in proportion to the density of the medium. . . . In the turbine blades themselves the efficiency is between 70 and 80 per cent."

Using this hydraulic analogy enables us to calculate



the row past which it leaks and the last row, because this reheating effect upsets calculations regarding openings by increasing the steam volume, and thereby affects the fluid efficiency. This leakage over the tips must be taken into account in designing reaction turbines. Temperature and diameter influence the clearance, and the stiffer the cylinder is to resist distortion due to heat, the less it may be made. A clearance diagram based on measurements off a large number of machines is given in Fig. 9.

In Table II. the vane speeds adopted in various classes of work are given, and the reduction in peripheral speed on account of the propeller reducing the revolutions, and the necessary proportion of blade height modifying the diameter, may be clearly seen. To this combined action is due the fact that only in the faster classes of vessels, or in those small types in which some propulsive efficiency can be sacrificed, is the turbine applicable. In slow cargo steamers, though the revolutions may be high enough, the power required is not sufficient to enable a reasonable blade height to be adopted, and it is this consideration—viz., proportion of leakage over blade-tips—that curtails the wider adoption of this type of turbine. For the same low peripheral blade speed other types of turbine are unsuitable on account of the impossibility of reducing the steam velocity sufficiently without abnormal weight and inefficiency.

The smallest size of marine turbine is usually larger than the average electrical turbine as far as power is concerned, and therefore does not meet with the same commercial considerations as the smaller sizes of the latter type. These are not designed for the same internal efficiency as the larger machines, chiefly on account of manufacturing cost, and they do not attain

the number of stages required in a different manner. The "equivalent head," due to the steam pressure, may

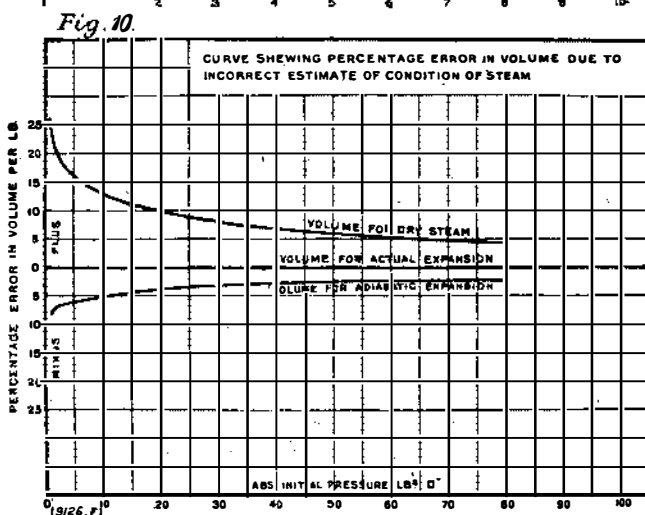
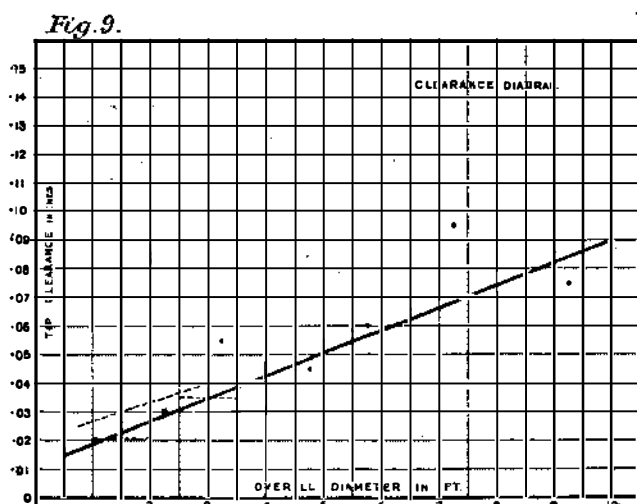
TABLE II.—Marine Work.

| Type of Vessel. | Peripheral Vane Speed. | | Mean Ratio of $V_t - V_s$. | Number of Shafts. |
|----------------------------------|------------------------|---------------|-----------------------------|-------------------|
| | High Pressure. | Low Pressure. | | |
| High-speed mail steamers | 70 to 80 | 110 to 130 | .45 to .5 | 4 |
| Intermediate speed mail steamers | 80 " 90 | 110 " 135 | .47 " .5 | 3 or 4 |
| Channel steamers | 90 " 105 | 120 " 150 | .37 " .47 | 3 |
| Battleships and large cruisers | 85 " 100 | 115 " 135 | .48 " .52 | 4 |
| Small cruisers | 105 " 120 | 130 " 160 | .47 " .5 | 3 or 4 |
| Torpedo craft | 110 " 130 | 160 " 210 | .47 " .51 | 3 " 4 |

Electrical Work.

| Normal Output of Turbine. | Peripheral Vane Speed. | | Number of Rows. | Revolutions per Minute. |
|---------------------------|------------------------|-----------------|-----------------|-------------------------|
| | First Expansion. | Last Expansion. | | |
| Kilowatts | | | | |
| 5000 | 135 | 330 | 70 | 750 |
| 3500 | 138 | 280 | 75 | 1200 |
| 2500 | 125 | 300 | 84 | 1360 |
| 1500 | 125 | 300 | 72 | 1500 |
| 1000 | 125 | 250 | 80 | 1800 |
| 750 | 125 | 260 | 77 | 2000 |
| 500 | 120 | 235 | 60 | 3000 |
| 250 | 100 | 210 | 72 | 3000 |
| 75 | 100 | 200 | 48 | 4000 |

be found, together with that at each row necessary to give the required velocity, from which both the num-



a radical departure in this, and adopt far higher speeds. The maximum vane speed used for the Parsons blading is, as far as the author is aware, about 375 feet per second in the low-pressure blades and 170 feet in the high-pressure blades of electrical turbines; the lowest speeds used are in marine work, and are only about one-third of these. To some extent blade speed is governed by blade height; the speed should

* Paper read before the Institution of Engineers and Shipbuilders in Scotland.

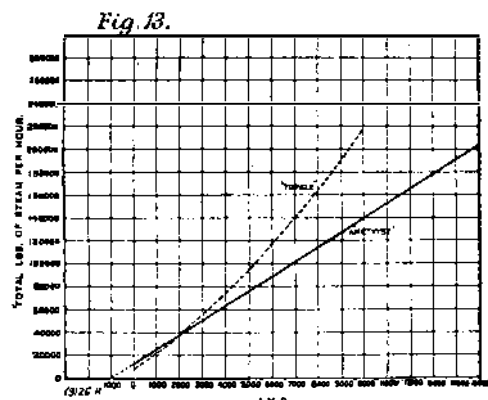
anything like the same efficiency compared with the Rankine cycle.

Speaking in reply to the discussion on his paper to the Institution of Naval Architects, in 1903, Mr. Parsons said that "for all practical purposes, while the steam is traversing each set (of blades), as shown, it behaves like an incompressible fluid, just like water would do, as the expansion is very small at each set. The frictional losses and the eddy-making losses would be practically identical within small limits with what

ber of stages and the coefficient of expansion at each stage may be worked out.

In the early marine designs, such as the "Queen Alexandra" and H. M. S. "Amethyst," the turbine drums were all made of the same diameter, and the higher speed necessary on the low pressures was got by running at considerably higher revolutions than on the high-pressure shaft; but, following up the increase in propeller efficiency found to be due to the use of larger screws, the speed for each shaft is now more

nearly equal, while the wing drums are made larger in diameter. The vagaries of the following wake, however, necessitate slightly different propeller dimensions on each shaft, or else slightly different revolutions with the same screws; and it is noticeable that in a triple-screw arrangement, the center screw being right-handed and the wing screws revolving outward, that the starboard propeller is influenced by the center one, and almost invariably revolves at a lower speed. In a four-shaft design, due to the varying wake values at different speeds, and possibly also to some unequal distribution of power, the outer screws run slower at low speeds, and faster at high speeds, than the two inner shafts; but exact data as to this, and the possi-



bility of allowing for it in the design, are still wanting.

In all types of turbines—the Parsons, the Rateau, the Curtis, etc.—a certain ratio must be maintained between the blade velocity and steam velocity; and as steam acquires very high velocities by expansion, the blade velocity must be maintained either by the revolutions, or by large diameters, or both. As the weight increases very rapidly with the diameter, and extraordinarily so with the reduction in rotative speed, it is preferable to increase, if possible, the revolutions or the number of stages rather than the diameter, and especially should this be done in cases where, as in the Rateau or Zoelly type, the weight increases more rapidly in inverse proportion to the revolutions per minute and the diameter than it does with other types. To increase the revolutions it may be necessary to increase the number of shafts and propellers, thus reducing the power per shaft and the effective thrust through each screw. Increasing the diameter of the turbine adds largely to the constructional difficulties, especially of the cylinder.

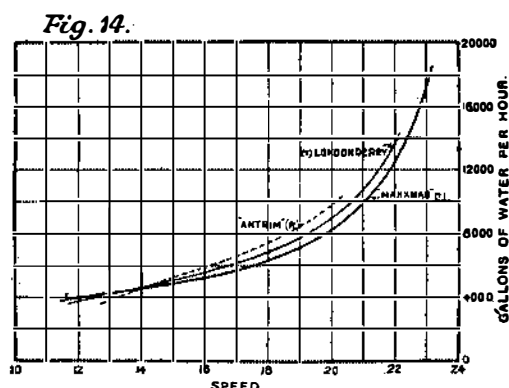
Having obtained the number of rows and the diameter, the blading arrangement can be worked out in detail. The height of blade depends on the volume of the steam and the speed at which it is to flow, and also on the ratio of the area of exit openings between the blades to that of the annulus between spindle and cylinder, which is about one-third in normal blades. The necessary clear area to pass the steam being equal to volume \div velocity, and knowing this annular factor, say 3, for a ratio of one-third (or 2 for $\frac{1}{2}$, etc.), then

$$\text{Height of blade in inches} = \frac{\text{Clear area in square inches} \times 3}{\text{Mean circumference in inches}}$$

The ratio of blade height to mean diameter should not be less than 3 per cent, or more than 15 per cent, because in the former the leakage will be excessive, and in the latter the bending moment on the blade becomes too great, and the radial divergence of the blades too much. The width of blade, the shape of section adopted, and the circumferential pitch are standard considerations, and affect the factor 3 given above. It is not proposed to enlarge upon them in this paper.

It may, however, be remarked that for $\frac{Vt}{Vs}$ greater

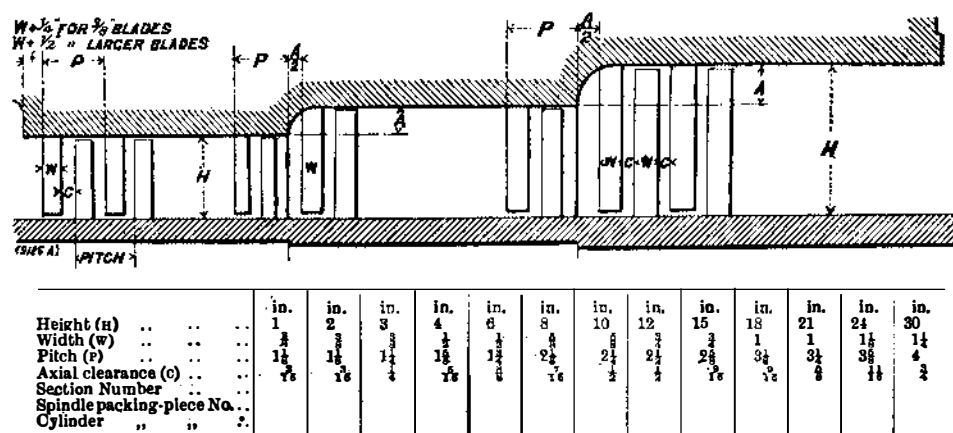
than 0.6 the usual shape of Parsons's section, as shown in Fig. 5, should be modified to a somewhat different form of blade, with a sharper entrance edge. This section is not to be recommended, as, owing to the necessity of strengthening the blade sufficiently, the metal



must be placed nearer the exit edge, thus increasing the angle between the face and the back of the exit edge of the blades, and giving, in fact, an inferior shape of opening compared with that obtainable with a blade section adapted to ratios under 0.6. If, for the present, it is sufficient to use the blade sections and packing pieces similar to those now adopted so generally, in Table III. can be found a list of widths for a given height, and the axial spacing of the rows. While this must be kept down to reduce the length of drum,

it must be sufficient to allow for some play in overhauling; and sufficient clearance can be allowed here without affecting the economy. The openings between the blades to allow of the passage of the steam are very important, and must be carefully designed. The actual volume of the steam—not the volume per pound, as found in tables, or the volume due to adiabatic expansion, but the exact volume per pound at any point along the turbine—must be determined, in order to

TABLE III.—STANDARD BLADING DIMENSIONS.



NOTE.—While the above represents general practice, it is obvious that such a table is largely arbitrary.

arrive at the desired adjustment of velocities. It is extremely doubtful whether the present blading arrangements give the best results; greater accuracy of calculation, and consequently improved pressure distribution and efficiency, seem likely to follow the use of a more mechanical blading construction.

Fig. 10 shows the percentage error involved in using either the dry volume or that due to adiabatic expansion, compared with the correct volume corresponding to the actual expansion in a large turbine using dry saturated steam at the first row of blades and 27 inches vacuum. Attention must be paid to the effect of approximately adiabatic expansion and the consequent moisture in the steam.

For manufacturing convenience, as well as to allow for the expansion of the steam, the blade heights are stepped up; but no rule exists for this; the blades might be of one or of sixty-four heights, provided the blade openings are correct. It is, however, convenient to step them, as in Fig. 5, say, in eight steps of eight each, or four of sixteen—even nine of seven would do—and so avoid any great variation from the annular area factor 3, as shown above. To obtain heights and areas, it is best to plot off graphically, volumes, steam speeds, and clear areas required. The use of standard blade heights will then enable the number of stages and rows per stage to be determined. Wide differences can be made in any arrangement without materially affecting the economy. The best arrangement is largely a matter of convenience and experience.

The material of which blades are usually made is a mixture of cheap brass, containing about 16 parts of copper and 3 parts of tin. Alloys containing zinc are extremely unreliable for high temperatures, but blades containing about 98 per cent of copper have been found very satisfactory for use with high superheats. More recently a material containing about 80 per cent of copper and 20 per cent of nickel has been adopted, and this is undoubtedly the best blading material existing. Steel blading, drawn in the same way as the usual brass section, has been used in the United States with fairly good results. The process of drawing turbine blades gives an extremely tough skin to the metal used, not only increasing the tensile strength, but greatly decreasing the chances of erosion.

It seems probable that the usual calking piece now adopted will be discarded in favor of a machine-divided strip, into which the blades may be fitted; and instead of the slotting, wiring, lacing, and soldering process at the tip, a similarly machine-divided shroud will be used, giving a far stronger construction, and enabling finer clearances and better workmanship to be obtained, at the same time considerably reducing the cost of manufacture and the risk of blade stripping.

The chief causes of the latter may be set down to bad workmanship in fixing the blades, defective blade material, excessive cylinder distortion (this is probably the most fruitful cause, and is a serious one, being due to bad design), whipping of turbine spindles (which is also due to bad design or bad balancing), wear of bearings (which is very remote), and the introduction of extraneous substances, such as water or grit. In fact, blade stripping may be said to generally occur from preventable causes. Small vibrations of very high frequency occasionally set up an action in certain rows of responsive length that fatigues the blade material, and causes the loss of blades without any fouling at all.*

Due to the action of the steam, an end thrust occurs in the direction of the propeller, which is advantageously used in partially balancing the propeller thrust, thereby reducing the size of thrust-block necessary. A margin must be allowed here, and the propeller thrust is not entirely balanced by the pressure on the annulus between the dummy-ring diameter, D , and the spindle, C , Fig. 5, plus the end pressure on the blades. For the diameter, D , to give the required annulus, as well as that of the propeller, the effective thrust must

* The writer had experience of this early in 1935, when a 5,000-kilowatt turbine, under test in one of the New York power stations, shed several rows of blades. This difficulty has also occurred in Europe, and can be circumvented by an alteration in the position of the lacing-strip.

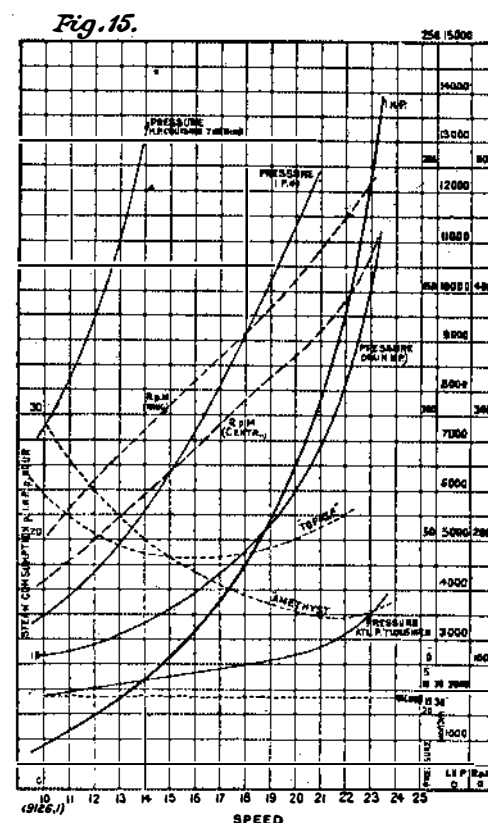
be carefully calculated; and experience shows that there is a drop in steam pressure varying from 10 pounds to 15 pounds per square inch between the pipe inlet to the high-pressure receiver and the first row of blades, which should be considered in designing this balancing area. The number of rows of dummy packing used varies, according to the designer's judgment, very largely, and may be modified according to the pressure and the clearance allowed—say 7-1000 inch

to 15-1000 inch in electrical work, and rather more in marine work.

The dimensions of the astern turbine are arrived at in the same manner as those of the ahead, the efficiency being largely sacrificed on account of weight and space; generally the mean diameter is made practically the same as that of the high-pressure drum.

To a large extent the inferior maneuvering capabilities of the earlier turbine steamers were due to insufficient astern power.

It may be remembered that in a marine turbine the



spindle is in compression and the cylinder in tension when working. In electrical turbines where the end-thrust must be eliminated by the use of balancing pistons, the spindle is in tension and the cylinder is balanced. The shafts between the turbine bearings and the drum must be made amply stiff enough, as well as strong enough, for any sag in the spindle will destroy the clearance. As will be seen from Fig. 11, the stresses due to centrifugal force are very low in the Parsons turbine, and, except in occasional low-pressure barrels, do not exceed 7,500 pounds per square inch, while at the high-pressure end they are usually under 2,000.

The pressure on the bearings in a turbine is only due to the weight of the spindle, plus the negligible addition, in marine work, of that due to any gyroscopic action; it may be taken as from 80 pounds to 90 pounds per square inch as long as the rubbing velocity does not exceed 30 feet per second. If it does, the pressure must be reduced so that the product of pressure \times the velocity does not exceed 2,500 to 2,700. In land work, 50 pounds \times 50 feet is very common. The friction heat of the bearings added to that due to conduction through the pedestals necessitates the use of large oil coolers, and in the case of very high temperatures, of special kinds of oil. If possible, the bearing temperature should not exceed from 140 deg. to 150 deg. Fahr., though the writer has known of 190 deg. Fahr. being used without trouble. In marine turbines this temperature is usually much lower. Rigid bearings are used for marine spindles—not the flexible type adopted in land work.

Space does not permit of more than passing reference to cylinders; but it would be difficult to exaggerate the importance of very careful design in this con-

nection. Cylinders, with heavy flanges on the center line, distort in a very curious fashion when heated with their axis horizontal, and measurements taken off a hot cylinder on a surface plate with micrometer gages reveal some very remarkable facts. When working, the temperature along the cylinder falls possibly from 400 deg. to 100 deg. Fahr. in a distance of 6 feet or 8 feet, and, unlike the reciprocating engine, this remains constant; the radial expansion is consequently more at one end than the other; while at any point

ward, taking with it the entire shafting. The thrust-block is at the forward end of the cylinder, and also performs the duties of an adjustment block for setting longitudinal clearances, to do which generally necessitates uncoupling the shafting abaft the turbine.

The difference in expansion between the cylinder and spindle, from the thrust-block to the dummy ring, may be the cause of serious difficulties in large marine turbines unless the closest attention is paid to this feature in the design; and "warming up" with these large

ing engines one stands on a comparatively cool lower platform with the cylinders overhead, and with some chance of the hot gases rising clear; but in naval turbine work, under a low deck, this point has not met with adequate attention.

In the course of operation, more especially in marine work, where no superheaters are used, there is a distinct tendency for the turbine to be supplied with wet steam, the effect of which on the economy is very marked. Experiments that have been made show that

TURBINE STEAMERS.—GENERAL DIMENSIONS AND DATA.

| DATE. | VESSEL. | SERVICE. | OWNER. | BUILDER. | Length. | Beam. | Depth. | Draught. | Speed. | Equiva- lent. | Number of Shafts. | Screws per Shaft. | Revolutions per Minute. | Roller Pres- sure. | Dis- place- ment. | Propeller Diameter. | REMARKS. |
|-------------------------|------------------------|----------------------------|---|---|---------|-------|--------|----------|--------|------------------|-------------------------|-------------------------|-------------------------------|--------------------------|-------------------------|------------------------|--|
| 1894 Rebuilt 1896 | Turbine | Experimental | C. A. Parsons | C. A. Parsons | 100 0 | 9 6 | .. | 3 0 | 32 | 2,000 | 3 | 3 | 2300 | 210 | 45 | 1 0 | Only one screw, 95 in. in diameter, now fitted to each shaft. |
| 1900 | King Edward | Pleasure steamer | Turbine Steamers, Ltd. | Denny Brothers | 290 0 | 30 0 | 10 0 | 6 0 | 20.45 | 3,500 | 3 | 1 Centre 2 Wing | 505 C. 760 W. | 150 | 700 | 4 4 | Put in service July, 1901. |
| 1901 | Queen Alexandra | Ditto | Ditto | Ditto | 270 0 | 32 0 | 11 6 | 6 6 | 21.43 | 4,400 | 3 | 1 | 760 C. 1090 W. | 180 | 920 | .. | Put in service July, 1902. Very largely used for experimental trials. |
| 1903 | Viper | Torpedo-boat destroyer | Royal Navy | Hawthorn, Leslie, & Co. | 210 0 | 21 0 | 12 9 | 6 9 | 26.58 | 13,000 | 4 | 2 | 1150 | 240 | 390 | 3 4 | Launched Sept. 6, 1903. Ran ashore, and lost during naval maneuvers in 1901. Trials made in 1900. |
| 1908 | Cobra | Ditto | Ditto | Armstrong, Whitworth, and Co. | 223 0 | 20 6 | 13 6 | 7 3 | 30.2 | 10,000 | 4 | 3 | 1050 | 210 | 450 | 2 8 | Sank at sea in Sept., 1901. |
| 1903 | Vindex | Ditto | Ditto | Hawthorn, Leslie, and Co. | 210 0 | 21 0 | 12 9 | 7 3 | 27.1 | 7,000 | 4 | 1 | 890 | 240 | 440 | 4 0 | Reciprocating engines on inner shafts, 24 in. in diameter and 16 in. in diameter, with 6 in. stroke; 490 r.p.m. Launched February, 1902. |
| 1904 | Eden | Coastal destroyer | Ditto | Thornycroft, Yarrow, and White | 220 0 | 23 6 | 14 2 | 8 3 | 26.2 | 7,500 | 3 | 2 | 940 | 250 | 570 | 3 3 | Twelve building. |
| 1905 | Oceanic | Coastal destroyer | Ditto | Laird, Thornycroft, and White | 173 0 | .. | .. | .. | 25.0 | 3,600 | 3 | 1 | 1300 | 220 | 225 | 3 0 | Five building. |
| 1905 | Experimental | Ditto | Ditto | Armstrong, White, and Hawthorn, Leslie, & Co. | 250 0 | .. | .. | .. | 23.0 | 15,000 | 2 | 1 | 700 | 280 | 800 | 6 0 | Details under consideration. |
| 1903 | Experimental | Ditto | Ditto | Yarrow | 330 0 | .. | .. | .. | 24.0 | 25,000 | 4 | 1 | 600 | 250 | 1500 | 7 0 | One 3-ft. screw now fitted to each shaft. |
| 1903 | Lorena | Ditto | W. K. Vanderbilt | Denny Brothers | 152 0 | 15 2 | 8 4 | 6 0 | 25.25 | 2,200 | 3 | 3 | 1800 | 225 | 145 | .. | Yacht measurement. |
| 1903 | Emerald | Ditto | A. L. Harbour | Denny Brothers | 253 0 | 25 3 | 20 4 | 13 0 | 18.02 | 3,800 | 3 | 1 | 800 C. 700 W. | 180 | 1000 | .. | Thames yacht measurement. Only twin-screw Parsons installation. |
| 1903 | Albion | Ditto | Sir G. Furness | Denny Brothers | 198 0 | 18 7 | 13 6 | .. | 15.0 | 1,400 | 3 | 1 | 900 | 150 | 900 | .. | In process of conversion from paddle engine to turbine. Vessel built in 1865 by Harland & Wolff. |
| 1903 | Narcissus | Ditto | Sir G. Furness | Denny Brothers | 270 0 | 27 0 | 16 3 | .. | 14.5 | 1,200 | 2 | 1 | 550 | 160 | 782 | .. | Staves specially arranged as in King Edward; 13 knots astern speed. |
| 1905 | Royal Yacht Maudslough | Ditto | H. M. King Edward | A. and J. Inglis (rebuilding) | 310 0 | .. | 25 6 | .. | 18 | 4,000 | 3 | 1 | .. | 150 | 2500 | .. | See Parsons installation. |
| 1905 | The Queen | Channel steamer | South-Eastern and Chatham Railway Company | Denny Brothers | 310 0 | 31 0 | 25 0 | 10 6 | 21.78 | 8,500 | 3 | 1 | 480 C. 560 W. | 160 | .. | .. | Staves specially arranged as in King Edward; 13 knots astern speed. |
| 1903 | Brighton | Ditto | London, Brighton, and South Coast Railway Co. | Ditto | 280 0 | 34 0 | 22 0 | 9 9 | 21.5 | 6,000 | 3 | 1 | 510 W. | 150 | 1500 | .. | See Parsons installation. |
| 1904 | Princess Maud | Ditto | Strait and Laine Service | Ditto | 300 0 | 40 0 | 24 6 | 10 6 | 20.7 | 6,500 | 3 | 1 | 800 | 150 | 1700 | 5 0 | See Parsons installation. |
| 1904 | Londonberry | Ditto | Midland Railway Company | Ditto | 330 0 | 42 0 | 25 6 | 10 6 | 22.3 | 7,000 | 3 | 1 | 870 C. 750 W. | 150 | 1900 | 6 0 | See Parsons installation. |
| 1904 | Manxman | Ditto | Isle of Man Steamship Company | Vickers Sons & Maxim | 330 0 | 43 0 | 25 0 | 10 6 | 23.14 | 8,500 | 3 | 1 | 880 C. 410 W. | 200 | 2000 | 6 0 | See Parsons installation. |
| 1905 | Viking | Ditto | South-Eastern and Chatham Railway Company | Armstrong, Whitworth, and Co. | 350 0 | 42 0 | 17 3 | 10 6 | 23.52 | 9,500 | 3 | 1 | 420 | 160 | .. | .. | See Parsons installation. |
| 1905 | Onward | Ditto | South-Eastern and Chatham Railway Company | Denny Brothers | 310 0 | 40 0 | 25 0 | 10 6 | 22.9 | 9,000 | 3 | 1 | 440 | 150 | .. | .. | See Parsons installation. |
| 1905 | Dieppe | Ditto | Great Western Railway Co. | Fairfield | 280 0 | 34 8 | 14 6 | 9 3 | 21.73 | 6,500 | 3 | 1 | 600 | 150 | 1300 | 6 0 | See Parsons installation. |
| 1905 | Princess Elizabeth | Ditto | Great Western Railway Co. | Ditto | 350 0 | 40 0 | .. | .. | 23 | 9,500 | 3 | 1 | 430 | 160 | .. | .. | See Parsons installation. |
| 1905 | Lhasa | Ditto | Belgian Government | John Brown and Co. | 350 0 | 40 0 | .. | .. | 24 | 12,000 | 3 | 1 | 400 | 150 | .. | .. | See Parsons installation. |
| 1904 | Loongana | Ditto | Hamburg-Helgoland Steamship Company | Cockerill | 340 0 | 38 0 | .. | 9 10 | 20 | 6,000 | 2 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1904 | Turbinia II. | Ditto | British India Steamship Company | Denny Brothers | 275 0 | 44 0 | 25 6 | .. | 18 | 6,000 | 3 | 1 | .. | .. | 2170 | .. | See Parsons installation. |
| 1904 | Mabeno | Ditto | Union Steamship Company | Ditto | 300 0 | 43 0 | 25 0 | 12 6 | 20.2 | 6,200 | 3 | 1 | 650 | 150 | 2400 | 5 3 | See Parsons installation. |
| 1905 | Bingra | Ditto | Union Steamship Company | Hawthorn, Leslie, and Co. | 295 0 | 33 0 | 20 9 | 9 6 | 19 | 3,500 | 3 | 1 | 650 | 160 | 1100 | 4 1 1/2 | See Parsons installation. |
| 1905 | Victorian | Ditto | Union Steamship Company | Denny Brothers | 450 0 | 50 0 | 33 6 | .. | 17.5 | .. | 3 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1905 | Carnegie | Ditto | Union Steamship Company | Workman and Clark | 300 0 | 60 0 | 42 6 | 27 6 | 19.5 | 12,000 | 3 | 1 | 275 | 180 | 13,000 | 8 0 | See Parsons installation. |
| 1905 | New Cunarders | Ditto | Atlantic Mail Service | Ditto | 540 0 | 60 0 | .. | .. | 21 | 21,000 | 3 | 1 | 185 | 195 | 30,000 | 14 0 | Also Virginian, built by Stephen & Sons. Weight saved by adopting turbines, 400 tons. Passengers increased 60. |
| 1904 | Amethyst | Third-class cruiser | Royal Navy | John Brown and Co. | 572 0 | 62 0 | 32 0 | 32 0 | 25 | 65,000 | 4 | 1 | 105 | 195 | .. | .. | See Parsons installation. |
| 1905 | Libelle | Scout cruiser | United States Navy | Armstrong, Whitworth, and Co. | 360 0 | 40 0 | .. | 14 6 | 21.75 | 9,500 | 3 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1905 | Chatter | Ditto | United States Navy | Vulcan Company | 241 0 | 43 3 | .. | 16 6 | 22 | 10,000 | 4 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1905 | Dreadnought | Ditto | Royal Navy | Bath Iron Works | 420 0 | 46 8 | .. | 16 0 | 24 | 16,000 | 4 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1905 | Orion Class | Ditto | Royal Navy | Fore River S. & E. Co. | 420 0 | 46 8 | .. | 16 0 | 24 | 16,000 | 4 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1905 | No. 243 | Experimental torpedo-boat | French Navy | Société des F. et C. Méditerranée | .. | .. | .. | .. | 21 | 23,000 | 4 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1903 | Caroline | Ditto | Ditto | Ditto | 182 0 | 15 3 | 8 4 | 5 0 | 26.4 | 2,200 | 3 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1904 | No. 293 | Torpedo-boat | Ditto | Yarrow | 125 0 | 14 0 | .. | .. | 26.5 | 2,500 | 3 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1904 | No. 294 | Ditto | Ditto | Normand | 125 0 | 14 0 | .. | .. | 26 | 2,500 | 3 | 1 | .. | .. | .. | .. | See Parsons installation. |
| 1905 | S. 225 | Torpedo-boat destroyer | Ditto | Schichau | 200 0 | 23 0 | .. | .. | 28 | 6,000 | .. | .. | .. | .. | .. | .. | See Parsons installation. |
| 1906 | Revolution | Experimental steam-turbine | Curtis Marine Turbine Company | .. | 140 0 | 17 0 | .. | 7 6 | 18 | 1,800 | 2 | 1 | .. | .. | .. | .. | See Parsons installation. |

Norm.—Also projected two vessels for the Great Central Railway Company, two for the Metropolitan Steamship Company (New York and Boston service), and various foreign warships.

† On trial.

along the turbine the tendency is to expand less at the flanges than at the top and bottom. For this reason ample clearance must be allowed; exactly what this will be when spindle and cylinder are hot is hard to say, but it seems most likely that the total clearance area will differ but little from what it is when cold.

The longitudinal expansion when hot is often very marked, and in all turbines necessitates provision for the resultant movement at one end. In marine work the after end of the cylinder is secured to the vessel, the engine-seating also performing the function of a thrust-block seat, while the forward end slides for-

cylinders needs possibly even more care than is essential with large piston engines.

On shipboard the turbine cylinders are practically under one's feet, and the radiation from them is very unpleasant, especially if there is any leakage from the glands. To all who are responsible for the lagging of cylinders and the system of ventilation in turbine engine rooms I would call attention to the possibility of their having to stand a watch of from four to six hours on the top of the high-pressure cylinder, such as is the case in the "Eden" or "Amethyst," the heat in the latter vessel being almost unbearable. With reciprocating

the percentage increase in consumption is about twice that of the moisture in the steam. For instance, with 2 per cent of moisture in the steam at the first row, the consumption is increased about 4 per cent.

A considerable amount of data on the performance of turbines, compared with reciprocating engines for marine work, is now available. The Admiralty has had tested both cruisers and torpedo boat destroyers exactly similar but for their engines and propellers, and trials of the Midland Railway Company's steamers and other cross-channel boats have corroborated the results regarding economy obtained from the naval

vessels. In Fig. 12 is given the steam consumption per unit of power of H. M. S. "Amethyst" compared with that of several recent warships, and it is noticeable that only below from 55 to 60 per cent of their full speed does the consumption of the turbine exceed that of the piston engines. Very seldom do vessels steam below these speeds. Cruisers carrying relief crews to China or Australian stations usually proceed at about 60 per cent of full speed, and in the Atlantic maneuvers of 1903 nearly 80 per cent of full speed was maintained by the large fleets, while the Japanese battleships built in England made their first voyage to Japan at about 50 per cent of their full speed; at which ratio the consumption per indicated horse-power of both the "Hindustan" and "Dominion," representing very recent battleship construction by eminent builders, is materially in excess of that of the first installation of warship turbines (not including the destroyers). The total consumption of H. M. S. "Amethyst" and "Topaze," plotted on a base of power, is given in Fig. 13, while Fig. 14 shows that for the Midland Railway boats.† The progressive trials of H. M. S. "Amethyst" are shown in Fig. 15, and in view of the results obtained from these various vessels, the wholesale adoption of turbine machinery in the Royal navy is not surprising.

It is probable that the adoption of cruising turbines will be discontinued before long, and this view seems to be corroborated by the consumption trials of the Midland Railway steamers. Down to 60 per cent of her full speed, the "Manxman" required less water than the highly efficient "Antrim"; and with a different blading arrangement in the main turbines, such a result should be equaled, if not improved on, in war vessels. The additional complication involved with two cruising turbines, and their accompanying leakage and receiver losses, together with a considerable increase in weight and space occupied, largely modifies any advantages obtainable in the way of reduced consumption at large powers. An improved (and easily obtainable) design of main turbine blading should give a better result at the highest powers, practically the same at intermediate powers (as in the case of H. M. S. "Amethyst," from 14 to 20 knots) and only slightly inferior at speeds below 14 knots, while it will undoubtedly admit of greater ease of handling and be much simpler. In a triple-shaft arrangement the unequal distribution of power on the wing shafts, due to the use of cruising turbines, is a distinct disadvantage; the fluctuation in rotative speed, due to shutting off the high-pressure cruising turbine, may be seen from the trials of H. M. S. "Amethyst."

One of the low-pressure rotors of the Allan Line steamer "Victorian" is illustrated by the photograph exhibited. This rotor is 8 feet in diameter, and carries eighty rows of blades, varying successively from 1½ to 7 inches in length.

Another photograph shows the complete blade rings of a Willans turbine, the machine-divided construction of which, coupled with the strong form of shrouding adopted, presents such great advantages over the present unmechanical system that its universal adoption may be expected in the near future.

In conclusion, the writer would remark that it is impossible in the scope of a paper such as this to touch more than lightly on a subject which is of such vast importance. Many of the points dealt with above, such as cavitation, blading, cylinder design, etc., would require a volume to describe. While turbines, perhaps, are still in their infancy, they are already largely supplanting the reciprocating engine in many types of vessels. The next few years will undoubtedly show as great an improvement as has taken place since the advent of the "King Edward," barely five years ago, the more especially as the subject will, henceforward, be engaging the attention of all engineers instead of a few specialists; and that this improvement will more than justify the policy of the Admiralty and of the Cunard Company is already certain.

It should be a matter of some satisfaction to the members of this Institution that the present status of the marine turbine, if not absolutely due to the Clyde alone, is, at any rate, entirely a product of Great Britain.

CATAPLEXY, OR FEIGNING DEATH.‡

MANY animals suddenly become motionless on the approach of danger. They are then said to feign death, but this expression, in so far as it implies a ruse, is misleading. An itch-mite, swimming under the microscope, stops when touched with a needle. Here the idea of a stratagem is absurd, as the creature can derive no advantage from immobility. But, as a mite has a distinct brain, let us take a simpler object, an amoeba, which retracts its pseudopodia on the slightest disturbance. Such a drop of protoplasm, whose mentality barely reaches the height of a nervous reflex, is surely incapable of feigning death.

These examples show that unusual stimuli cause even the lowest animal forms to contract and become motionless, and it might reasonably be expected that this primitive impulse would be greatly intensified and perfected in some higher animals, while in others it would be entirely lacking, because useless.

That higher animals may become motionless under the influence of unusual conditions, especially such as

cause intense fear, is suggested by the common expression "stiff with fright." This effect of terror, which is known as cataplexy, is analogous to the effect of unaccustomed stimuli on mites and amoebæ. The first experiments on the subject were published by Athanasius Kircher in 1646. He observed that a fowl, laid on the ground with its feet tied together, would, after some ineffectual attempts to escape, lie perfectly still. Then, if a chalk line were drawn on the ground, straight from the fowl's head, and its legs were un-



FIG. 1.—FINCH IN CATAPLECTIC STATE.

bound, it would remain motionless despite attempts to drive it away.

The experiment has been repeated, and extended to other animals, by many later investigators. The chalk line is useless. The chief condition of success is that the animal be seized suddenly and firmly held for a time. In this way cataplexy can be induced in many birds, guinea pigs, frogs, squirrels, moles, etc.

The same phenomenon is often observed in wild life. It cannot be a means of defense because usually the immobility, occurring at the moment of greatest danger, is fatal to the animal. For instance, the partial paralysis which, according to Prince von Wied, the sight of a venomous snake induces in Indians must be highly inconvenient.

Besides, it has often been observed that lizards pursued by snakes at first seek safety in flight but, when they find escape impossible, become motionless and seem to await death. Lizards appear to be peculiarly subject to cataplexy, which Preyer induced in some large lizards by quickly turning them on their backs, to the astonishment of the conjurers who were exhibiting them. Mice, squirrels, and other small animals, also, are fascinated and paralyzed by snakes, whence the immemorial popular belief in the hypnotic and magical powers of serpents. The fable of the basilisk probably rests on the same foundation. Pliny mentions, in his Natural History, an African animal, called Katablepas (looking downward), which carries



Fig. 2.—Burying beetle (Hister). a, cataplectic; b, normal.

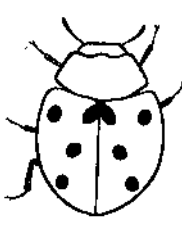


Fig. 3.—Ladybird in Cataplectic State.

its head bowed to the ground, fortunately for the human race, for whoever looks into its eyes dies instantly.

Hunters frequently observe cases of cataplexy. Preyer says: "I have often seen partridges which had been shot in the leg fall to the ground, lie motionless for a considerable time, and then fly away. There can be no doubt that they had fallen into cataplexy when shot. Deer struck by glancing bullets also remain motionless. Even when they fall they are often found to be not mortally wounded but merely paralyzed by fright."

Hunters of certain animals reckon upon the aid of cataplexy. In Iceland, when the young swans come from the interior to the coast in autumn, they are greeted with a tremendous uproar, which causes them to fall to the ground, where they are easily captured. In German Southwest Africa the Hottentots employ a similar method in hunting the "springhaas," Cape jerboa or Cape hare. They beat the bush by moonlight, and, when they see a "hare" creeping from its hole, throw themselves on the ground and raise a horrible din. The poor beast, paralyzed by fright, remains motionless until the hunters creep to it on all fours and kill it with their clubs.

From these examples it is evident that cataplexy is not always beneficial, for immobility does not assure safety unless it is combined with other favoring con-

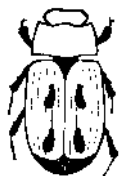


Fig. 4.—Dung-beetle, dead.



Fig. 5.—Dung-beetle in cataplectic state.

ditions. If, for example, an animal possesses stout armor, within which it can retract its head and limbs, immobility may be of great service to it. The best and most familiar case in point is that of the tortoise. Darwin describes the giant tortoises (*Testudo nigra*), formerly so numerous in the Galapagos Islands, as hissing at his approach, retracting their heads and legs, falling noisily to the ground, and lying as if dead.

Often he seated himself on the animal's back and slapped it until it awoke and crawled off with him, but he adds that he found it difficult to maintain his equilibrium. Among other animals which act in a similar manner, and likewise to their advantage, are mussels, snails, hermit crabs, caterpillars, tube-worms, wood-lice, hedgehogs, and armadillos.

In the Revue Scientifique, last year, Piéron asserted that the case of insects which "feign death" is essentially identical with that of tortoises. Most of these insects also have strong armor beneath which the tender limbs can be retracted, thus reducing the area of surface exposed to attack. But, in the first place, not all insects retract their limbs in the cataplectic state. Darwin has pointed out that with many the simulation of death is imperfect. Among these are the burying beetles (*Histeridae*) so abundant in spring. Their popular German name, *Stutzkafer*, or balking beetles, is derived from their habit of stopping short on encountering unfamiliar objects. One which I observed stood motionless sixteen seconds on coming to a wall or chair-leg or when I rose to my feet beside it, but it did not always entirely retract its antennæ. Many of the little beetles so often seen running along sandy paths stop from half a minute to two minutes when startled by a footstep or otherwise, but they retract neither their antennæ nor their legs. Another novice in the art of feigning death is the ladybird. This pretty little creature sometimes remains motionless ten minutes, retracting an indefinite number of its appendages and leaving the rest exposed. Many pages could be filled with similar examples.

Hence it is not true that cataplectic insects always retract their limbs in order to diminish the exposed surface. Besides, such diminution would be of questionable advantage against large enemies. A bird does not seize a beetle by the leg but swallows it whole. Small enemies, such as ants, on the other hand, can attack a limb even when it is pressed close to the body. I think, therefore, that the cataplectic phenomena of insects are not directly comparable with those of tortoises and other armored animals.

That the cataplexy of insects is not a ruse appears from the fact that it usually terminates long before the danger is past. Besides, the attitude assumed is generally very different from that of death. For example, the limbs of the dung-beetle (*Aphodius*) are extended in death, while in cataplexy they are retracted.

Insects exhibit great variety in respect to cataplexy. Some species, including the most active and most capable of self-defense, never fall into that state and among species that normally do so individuals are found that do not. Another interesting fact is that many individuals can be almost cured of the habit by familiarizing them with disturbance. I have often observed that beetles which at first stopped short at every alarm proceeded calmly on their way after repeated disturbances. The duration of immobility also diminishes when cataplexy is often induced. A carrion beetle (*Silpha atrata*) at first remained motionless thirty-five seconds, but repeated cataplexy shortened the period to fifteen seconds. Herrera has also observed cures of cataplexy by repeated disturbance. There are many species, however, to which this does not apply.

All these things indicate that cataplexy is of reflex character, and analogous to swooning. This view is confirmed by the fact that immobility is usually not absolute. A ladybird lay quite still for six minutes, then moved its forelegs, feebly at first and then more energetically. A minute elapsed before the hind legs moved, and two more before the insect ran away. Its first steps were uncertain and staggering. I have observed similar phenomena in individuals of many species. So the usual assertion that the insect awakes and escapes suddenly is not universally true. The first movements are often of a trembling, convulsive character.

Cataplexy, furthermore, is affected by environment and bodily condition. Once I found a beetle which had lost a leg and a wing cover. When touched it lay with limbs extended and awoke in four seconds, though normal individuals of its species remain long motionless, with retracted limbs. Another beetle, when near death from starvation, could not be brought into cataplexy.

Cataplexy is also prevented by decapitation. This fact proves that the brain plays an essential part in the phenomenon. Beheaded pine-weevils (*Hylobius* and *Otiorynchus*), when touched, continued to move, usually backward.

According to Piéron, cataplexy depends on the absence of a hiding place. He found that beetles (*Dermestes* and *Gestrupe*) usually fled to the nearest refuge, falling into cataplexy only when no shelter was at hand. When turned on their backs, however, they always lay motionless, with legs drawn up, for a considerable time, finally righting themselves after protracted efforts. If touched during these struggles they relaxed into immobility. The disturbance lost its effect by frequent repetition, and a prick with a needle awoke the insect instantly.

But though I have observed more than one hundred species I have never detected the slightest effect of the presence of a hiding place. Dung-beetles (*Geotrupes*) surrounded by a ring of dung behaved precisely as they did in the absence of shelter. There is a red species that abounds in cow dung. When the crust of their paradise was removed they were found lying motionless on the surface. If the presence of shelter prevents cataplexy they should have buried themselves at the first alarm, as they did on awaking from their swoon.

Of the cases in which cataplexy is of advantage to

* Since the above-mentioned results were obtained, the steam-piping has been altered, so as to permit the auxiliary exhaust steam to pass through the main low-pressure turbines when desired. This arrangement considerably decreases the consumption of low speeds, bringing the Amethyst's consumption below that of her sister-ships down to 10 knots, or about 45 per cent of full speed.

† Fig. 14 is compiled from the results given in Mr. Gray's paper to the Institution of Naval Architects, July, 1905.

‡ Condensed from Dr. Walther Schoenichen in Prometheus.