The theoretic quantity of coal consumed by the ammonia process then becomes $3.8 + 16.75 = 20.57$ kilos. (against the 3.6 kilos. by the sulphurous acid process.

14A. It is noted in the original that the above estimate does not include the power for driving the feed pump or for agitating the liquid, and there is estimated at least 1.5 kilos. for these purposes and for the force expended in the transmission, and reference is made to lines of theoretic and practical effect of ammonia ice-making machines which do not seem founded on any reliable data or experimental basis. This portion of the paper would be more satisfactorily presented if it had the authorization of the maker of the Carré machine.]

STEAM ENGINE GOVERNORS.

By J. HAUG, M. E.

The application of the conical pendulum as a governor to the steam engine dates from the time of Watt, and although countless modifications of this principle have been patented since that time, and certain advantages claimed for each of these, yet the general opinion of engineers conversant with this subject is, that only few of them can really be considered superior to Watt's, while, as regards simplicity, the latter has decidedly the advantage.

The two forces acting in a conical pendulum are:

The weight of the ball (W in Fig. 1) acting vertically downward, and the centrifugal force C , acting horizontally outward. Constructing a parallelogram of forces, the resultant

R will give the angle α' , at which equilibrium is attained. Then as angle α is equal to α' , and the triangles ABD and BRW are similar, it follows that their respective sides are of the same proportion, or

Fig. 1.

$$\frac{h}{r} = \frac{W}{C} \quad (1)$$

i. e., the height of suspension is to the radius of revolution as the weight of the ball is to its centrifugal force.

But the latter is :

$$C = \frac{(2\pi n)^2 r W}{g}$$

where n = number of revolutions per second and g = unit of gravity = 32.166 feet.

Introducing this term in Formula (1), we have

$$h = \frac{W g r}{(2\pi n)^2 W r} = \frac{g}{4\pi^2 n^2} = \frac{0.81452}{n^2} \text{ in feet.}$$

or if n_1 = number of revolutions per minute,

$$h = \frac{2993}{n_1^2} \text{ in feet.} \quad (2)$$

and

$$n_1 = \sqrt{\frac{2993}{h}} \quad (3)$$

Fig. 2.

Fig. 3.

Fig. 4.

Wherever the joints of the arms may be situated, h is always the vertical distance from centre of ball to intersection of arm with the centre line of spindle, as shown in Figs. 2 and 3, which will be evident when it is considered that the centrifugal force is directly proportional to the radius of revolution.

In the above demonstration no account has been taken of the weight of arms and other gear connected with the governor.

Taking now (Fig. 4), $a = AD$, $-b = AC$.

W = weight of ball + half the weight of suspension rod.

P = weight of collar B + weight of other gear not balanced.

$$\text{Then } n_1 = \sqrt{\frac{2933}{h} \left(1 + \frac{P b}{W a} \right)} \quad (4)$$

While the force exerted by P is added to the force W (Fig. 1) in proportion to its leverage, it cannot increase the centrifugal force, which, to attain equilibrium, has to be augmented by a greater number of revolutions, as obtained by Formula (4).

Fig. 5.

Fig. 6.

In Porter's governor, as first applied to the high-speed Allen engine, we find the extreme application of this idea (Fig. 5); the balls are made very small, and the heavy central weight is balanced by a greater number of revolutions.

In place of a central weight, springs of different shapes have been applied, but, owing to the resistance of a spring increasing with its deflection, its action is somewhat different from that of a weight.

Fig. 6 shows the extra weight adjustable on a lever; by shifting it in or out the governor may be made to regulate for a smaller or greater number of revolutions.

The ordinary governor has the great disadvantage of not being isochronous or "equal timed"; at the normal speed of the engine, the arms can only be in one certain position, corresponding to a certain position of throttle or cut off. An increase or decrease of load will necessitate a change of throttle or cut off, and a corresponding position

of governor, which can only be attained by a proportional decrease or increase in the number of revolutions.

To overcome this difficulty, a great many isochronous governors have been brought out, of which the "parabolic" governor may be taken as *theoretically* perfect.

Fig. 7.

In a common parabola (Fig. 7), all "subnormal" lines, *i. e.*, the vertical distance h of the intersection of a line normal to the curve (as $a b, c d$, etc.) with the centre line from its intersection with the parabola, are equal, and if the centre of a governor ball moves in a parabola, such a governor would be in equilibrium at all positions for the same number of revolutions, but would immediately go up or down at a change of speed. If now the changed position of the governor does not immediately produce a return to the normal speed (which is not always possible) the governor will

fly to its extreme position, the throttle or cut off will be changed too far, and an opposite change of speed will send the governor to its other extreme, and thus the speed of the engine will continually change above and below its normal speed.

Fig. 8.

Fig. 9.

Fig. 8 illustrates graphically the action of the common governor: Line $A B$ represents the normal speed, $C D$ the increased speed, which, at a decrease of load, is necessary to keep the governor in a higher position, and this speed continues until an increase of load, requiring a lower position of governor (to effect corresponding change in throttle or cut off) makes a speed below the normal imperative, as shown

at $F E$, and this speed again continues until another change of load requires a different speed and position of governor, or until a return to the normal load again establishes the normal speed and position.

The action of an isochronous governor, as described above, may be graphically illustrated by Fig. 9; where $A B$ is the normal speed and $C D$ the continual change of speed above and below $A B$, produced by the instability of the governor. To remedy this defect, some kind of resistance, which could not be overcome too quickly, would have to be opposed to the action of the governor, but at the cost of sensitiveness; an air cushion (which should be double acting) would be least objectionable, as a spring, owing to its resistance increasing with its compression (and *vice versa*), would destroy the isochronous property of the governor.

By a very slight modification the Watt governor may be made sufficiently isochronous for most practical purposes.

If the arms are suspended on the opposite side of the centre line (Fig. 10), an approximation to the parabolic governor is obtained, A being the centre of a circular arc, which, for a movement through a few degrees, will nearly coincide with a parabolic curve, and therefore such a governor will be nearly isochronous.

To show the percentage of deviation, the following example is a comparison of the ordinary Watt (Fig. 4) with the last-named governor:

Taking the arms $A D = a = 20''$ long, $B C = A C = b = 10''$, the normal angle $\alpha = 30^\circ$, the extreme angles $\alpha_1 = 20^\circ$ and $\alpha_2 = 37^\circ$, the lift of the sleeve will be, for all three systems of suspension, $= 2 b (\cos. \alpha_1 - \cos. \alpha_2)$ consequently each will do the same work.

h will be for Watt's governor $= a \cos. \alpha$.

Fig. 10.

for $30^\circ = 17.32$ inches.

“ $20^\circ = 18.79$ “

“ $37^\circ = 15.97$ “

for improved governor : (taking $E A = B F = e = 2''$)

$$h = a \cos. \alpha - e \cotg. \alpha,$$

for $30^\circ = 13.856$ inches.

“ $20^\circ = 13.3$ “

“ $37^\circ = 13.316$ “

According to Formula (4), n_1 would then be, $\left(\text{if } \frac{P}{W} = \frac{2}{3}\right)$ for the ordinary governor—

for $30^\circ = 52$ rev. per min.

“ $20^\circ = 49.9$ “

“ $37^\circ = 54.2$ “

thus showing a deviation below the normal speed of $\frac{2.1 \times 100}{52} = 4$ per cent., and above of $\frac{2.2 \times 100}{52} = 4.2$ per cent., a total of 8.2 per cent.

For the improved governor n_1 would be

for $30^\circ = 58.2$ rev. per min.

“ $20^\circ = 59.4$ “

“ $37^\circ = 59.4$ “

a deviation of $\frac{1.2 \times 100}{58.2} = 2$ per cent.

A governor with arms jointed outside of centre line (Fig. 2) would have $h = a \cos. \alpha + e \cotg. \alpha$:

for $30^\circ = 20.784$ inches.

“ $20^\circ = 24.28$ “

“ $37^\circ = 18.624$ “

and n_1 would be :

for $30^\circ = 47.5$ rev. per min.

“ $20^\circ = 44$ “

“ $37^\circ = 50.2$ “

a deviation of $\frac{3.5 \times 100}{47.5} = 7.35$ per cent below, and $\frac{2.7 \times 100}{47.5} = 6$ per cent. above the normal speed, a total of 13.35 per cent.

The last-mentioned construction is thus shown to be most deficient in isochronism, and many attempts have been made to correct this fault. One of the latest is the Gardner governor (Figs. 11 and 12), where a toe on the end of the suspension arm presses transversely against a toggle joint combination, which is connected to a weight or spring pressing upwards, thus tending to compress the toggle joint vertically, forcing it outward against the toes of the governor arms.

Fig. 11.

Fig. 12.

When the governor arms are down, the toggle joint being more compressed vertically, exerts greater pressure horizontally against the governor arms; to counteract this the centrifugal force must be increased by a few revolutions, bringing the speed nearer to the normal, and exactly the opposite action occurs, when the governor arms move above their normal position.

A recent test of this governor at the Franklin Institute gave a deviation of from 6 to 14 per cent. from the mean speed, hence its isochronism is very far from being perfect.

Siemens' differential or chronometric governor consists of a conical pendulum with heavy balls, driven by a train of bevel wheels, as shown in Fig. 13. The shaft *a* receives its motion from the engine, and has keyed on its end a bevel wheel, *b*, which gears into another similar wheel, *e*, that can vibrate around the vertical axis *A B*, but is held in position by the weight *g*, acting through lever *f* and rod *c*. The wheel *e* gears into the wheel *d*, which is fixed on the shaft of the pendulum, and thereby the latter is put into motion.

The weight *g* is adjusted to balance exactly the tangential force of weight *a*, necessary to drive the pendulum at the normal speed; if now

the engine (and with it shaft *a*) changes its speed, the pendulum, on account of its inertia, will still continue its uniform speed, which causes the wheel *c* to swing around the axis *A B*, and the lever *f* being fixed on a shaft connected with the throttle or cut off, these will be changed correspondingly.

Fig. 13.

As the power necessary to drive the pendulum at a certain speed may be considered uniform, the wheel *c* will only be at rest as long as this speed is maintained, but (within a certain limited travel of lever *f*) it may be in different positions; and as thereby different positions of throttle or cut off, corresponding to the load to be overcome by the engine, can be attained without a permanent change of speed, the governor may be called perfectly isochronous.

As in some cases the shifting of throttle or cut off gear may require more force than a change in speed of the pendulum, the latter has an ingenious arrangement, by which a slight rise or fall of the pendulum balls will increase that force.

The ordinary Watt governor may act indirectly upon the throttle or cut off, as shown in Fig. 14. The sleeve *a* of the governor is connected by lever *j* to a clutch, *c*, which, being between two bevel

wheels, *d* and *e*, running in opposite directions, is put into gear with either by a rise or fall of the governor balls. This clutch slides upon a feather in the screw *f*, which, by means of nut *g*, lever *h* and rod *i*, can move the throttle or cut off.

Here the governor acts with perfect isochronism, as it is evident that at any change of speed the clutch will remain in gear until the normal position and number of revolutions is regained.

As the force moving the throttle is derived from the engine direct, the governor is extremely sensitive, but this advantage is sometimes more than counterbalanced by the time required to effect any considerable change in the throttle or cut off, and for this reason, and on account of the additional complication, this system is but little used.

Buss's "Cosine Governor" derives its name from the fact that its moment of centrifugal force is proportional to the cosine of the angle of deviation γ for an entire revolution round its point of suspension *c*. When connected to a central weight, *W*, in such a way that the moment of this weight, acting against an arm, *b c*, of the pendulum, is also proportional to the cosine of the angle of deviation, a perfect isochronous governor is obtained, having the greatest possible range of motion, consequently possessing great power and sensitiveness. Fig. 15 shows that each arm of the pendulum has two balls, fixed at 90° to each other, which are suspended from a point, *c*, situated in the central weight; the arms *c b* bear against a fixed shoulder on the spindle, and the centrifugal force of the balls has to balance both the central weight *W* and the weight of the balls, hence all parts are utilized to increase the power and sensitiveness. By a small change of the angle *s c b*, a nearly uniform degree of stability with only a limited deviation from isochronism can be obtained, thus obviating the most serious defect of isochronous governors—their instability.

The theory of this governor, as given by the inventor, is as follows :

Fig 14.

mon centre of gravity of a system of bodies from any point is equal to the sum of the moments of the parts with regard to this same point, divided by the sum of their weights.

If l is the distance $c s$, $x_1 = l \cos. \gamma$ and

$$M_c = \frac{\omega^2}{g} r Q l \cos. \gamma + \frac{\omega^2}{g} \sum q x_1 y_1 \quad (7)$$

If the weight of the revolving body is divided into such parts that their moments, $q x y$ and $q x_1 y_1$ are equal, but opposite, $\sum q \frac{\omega^2}{g} x_1 y_1$ (Formula 7) will be $= 0$, and this will always be the case where the parts are at 90° and their moments, with regard to their common centre of gravity, s , are equal, of which some examples are given in Fig. 16.

Fig. 16.

In each of these cases (taking $f = c a$): $q x y + q_1 x_1 (-y_1) = q f^2 \cos. (45+\gamma) \sin. (45+\gamma) + q f^2 \cos. (45-\gamma) (-\sin. 45-\gamma) = 0$, hence $M_c = \frac{\omega^2}{g} r q l \cos. \gamma$. (8)

i. e., proportional to the cosine of the angle γ .

In applying the central load, W , the weight of the balls, having the moment $= Q l \sin. \alpha$, must be taken into account, and the angle $c s b = \beta$ will have to be so arranged that

$$Q \frac{\omega^2}{g} r l \cos. \gamma = (W+Q) b \sin. (\beta-\gamma) + Q l \sin. \gamma,$$

to make the governor perfectly isochronous, and this is obtained by making

$$\cos. \beta = \frac{Q l}{(W + Q) b}$$

From Formula (2) it is apparent that theoretically the weight of the balls has no influence on the position or number of revolutions of a pendulum, as the centrifugal force increases in the same ratio with an increase of weight, but in its practical application this point is of some importance; to overcome the resistance of the gear there must be a cer-

Fig. 17.

tain increase or decrease of the centrifugal force before the governor can act.

If n = normal number of revolutions,

n_1 = lowest and

n_2 = highest number of revolutions permitted,

then $\delta = \frac{n_2 - n_1}{n}$ = total deviation.

For n the centrifugal force is:

$$C = (2 \pi n)^2 \frac{W}{g} r$$

and for n_2 :

$$C_2 = (2 \pi n_2)^2 \frac{W}{g} r$$

and the difference :

$$A C = 4 \pi^2 (n_2^2 - n^2) \frac{W}{g} r$$

or, approximately :

$$\Delta C = \delta 4 \pi^2 n^2 \frac{W}{g} r;$$

its leverage being $= h = \frac{g}{4 \pi^2 n^2}$,

its moment is :

$$\Delta C h = \delta \frac{4 \pi^2 n^2 W r g}{4 \pi^2 n^2 g} = \delta W r. \quad (9)$$

If Q = resistance of gear referred to sleeve B ,

$$b = A C,$$

$$a = A D,$$

this action of Q will produce a force $= \frac{Q}{\cos. \alpha}$ in the direction of BC ,

which, with regard to A , will act with a leverage $A F = b \sin. 2 \alpha$,

hence its moment $= \frac{Q b \sin. 2 \alpha}{\cos. \alpha}$. (10)

Putting $Q \frac{b \sin. 2 \alpha}{\cos. \alpha} = \delta W r$, the weight of balls is found :

$$W = \frac{Q b \sin. 2 \alpha}{\delta r \cos. \alpha}.$$

and as $r = a \sin. \alpha$, and $\frac{\sin. 2 \alpha}{\cos. \alpha \sin. \alpha} = 2$, $W = \frac{Q 2 b}{\delta a}$

or each ball : (11)

$$\frac{W}{2} = \frac{Q b}{\delta a}$$

showing that, for any considerable resistance, very heavy balls or an extensive deviation of speed from the normal, would be needed, to effect a change in the throttle or cut off gear.

A governor, loaded with a central weight (Fig. F.), has an advantage in this respect, as its greater angular velocity (necessary to balance the central weight) will give a greater differential moment of centrifugal force for a certain change of speed than the ordinary construction.

Here $h = \frac{g}{4 \pi^2 n^2} \left(1 + \frac{P b}{W a}\right)$ [see Formula (4)], making the differ-

ential moment of centrifugal force : $\Delta C h = \delta \frac{4 \pi^2 n^2 W r g}{4 \pi^2 n^2 g} \left(1 + \frac{P b}{W a}\right)$

$$= \delta W a \sin. \alpha \left(1 + \frac{P b}{W a}\right) \quad (12)$$

and putting this equal to the moment of resistance of gear :

$$= \frac{Q b \sin. 2 \alpha}{\cos. \alpha} \text{ will give}$$

$$W = \frac{Q 2 b}{\delta a \left(1 + \frac{P b}{W a}\right)}; \quad (13)$$

Thus if $\frac{P b}{W a} = 1$, the weight of balls will only be one-half of that needed for the ordinary governor, to overcome the same resistance, or balls of the same weight would already act at one-half the deviation of speed from the normal, thus doubling the sensitiveness of the governor.

In conclusion it might be well to point out that a sensitive governor is not the only thing necessary to ensure uniformity of motion.

Not only the load may be variable, but the pressure at different parts of a revolution also varies, especially in engines working expansively, and when the steam is cut off, the influence of the governor is cut off also, hence the fly-wheel ought to be heavy enough to store up any excess of work developed during that time, without greatly increasing the speed, otherwise the governor, especially if it is very sensitive, will always be flying up and down, thus defeating its very object.

Systematic Errors.—Otto Struve states that his measurements, especially those of direction, are subject to very large systematic errors, depending upon the angle between the direction of the two stars and the vertical circle at the moment of observation. By means of measurements taken upon artificial stars, he has determined the corrections with great exactness and has proved that the same laws of error have existed in his case for the last 35 years. He supposes that they have a physiological origin depending upon the construction of the observer's eyes. He thinks it desirable that every astronomer who is employed upon similar measurements should make special experiments so that the results of different observers can be more satisfactorily compared.—*Comptes Rendus.* C.