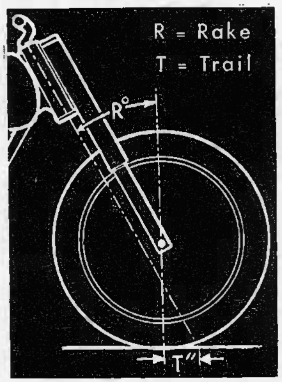
MOTORCYCLE ENGINEERING—1



Steering Geometry

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General stability problems of the two-wheeler and their effect upon the basic theory of "front end" design

A MOTORCYCLE in solo form is unable to keep itself upright because it is supported only at two points in the central plane and the whole of its weight is above these points. Consequently the slightest deviation from the vertical, or the application of a side-force as from a gust of wind, will cause it to fall. Given only a modicum of forward speed, however, it can be maintained upright by the skill of the rider, and above a certain minimum velocity it will balance itself if correctly designed. Moreover, a good example will proceed in a straight line even on irregular surfaces with no guidance at all, thus achieving a condition known as "auto-stability."

To some extent, a child's hoop behaves in the same way. It will travel in a straight line above a certain speed, but below that speed will incline to one side or the other and proceed to run in ever-decreasing circles until it falls flat. An interesting point is that it can only be prevented from circling by a correcting touch at the *top*. It cannot be steered back into line by applying the stick to the outer side at the rear of the hoop; in fact, this will only hasten the fall.

Gyroscopic Effect

The hoop runs straight because it is, in effect, a gyroscope rotating round an invisible axle. When it starts to fall, say, to the left and thus runs to that side, it acquires an anti-clockwise angular velocity, viewed from above. This immediately creates an effect known as "gyroscopic precession," which sets up a force—or, more correctly, a couple—tending to return the hoop to the vertical position (see Fig. 1).

Moreover, the displaced hoop becomes subject to centrifugal force acting radially outward. This force also tends to restore the hoop to the vertical, whereupon it again runs straight and the centrifugal force vanishes.

As the forces are proportional to the weight of the hoop they are just sufficient to maintain equilibrium above a certain minimum speed. And as the corrections are applied automatically and instantaneously the hoop always runs straight unless violently deflected, in which event it may follow a sinuous path until stability is again reached.

In a single-tracker with a steerable front wheel, somewhat the same processes take place, but conditions are very different because the weight to be kept upright is many times greater than the weight of the rims and tyres, which supply most of the gyroscopic forces. The rear wheel, being fixed in relation to the frame, can only play a part so small as to be insignificant—though, as we will see later, it can become the villain of the piece and really upset the steering if it is capable of being deflected from its true position.

Fig. 1. The principle of gyroscopic precession: A bicycle wheel is spun clockwise (viewed from the operator's right). When he swivels the wheel about its vertical axis anti-clockwise (viewed from above), it will tilt to the right.

Though it is possible to maintain balance on a two-wheeler which has the front fork and steering column in a line drawn vertically through the axle, as in the old velocipedes, the thing would be very difficult to handle on any but a dead-smooth surface, because if the wheel struck a bump the point of contact would necessarily be forward of the steering axis and, unless forcibly held, the wheel would be knocked round to full lock. This condition is overcome, and the steering tends to maintain a straight-ahead position naturally, if the wheel is given some "trail," i.e. if its axle is moved in relation to the column axis so that the theoretical point of tyre contact lies some distance to the rear, so providing a castor action.

Why Rake?

If trail is applied while still retaining a vertical column, the wheel is likely to develop a wobble, for reasons which are a little too complicated to delve into here. However, if the axis of the column is laid backwards at a considerable angle, or "raked," and the position of the axle then re-adjusted to furnish the required amount of trail, one arrives at a steering system which can be very good indeed—if it is exactly proportioned to the rest of the model. If it is not, then one may get something which is heavy on corners, or becomes uncomfortably light and tends to wander at speed, or develops front-wheel wobble.

Endeavours have been made to derive a formula by which wobble-free steering may be designed into a machine, but there are so many factors involved, some of which can only be assumptions at best or wild guesses at worst, that empirical methods, based on known data, are probably the safest in the original design stage. It may well be, in fact it is practically certain, that some adjustments will be required later.

It is not always appreciated by motorcyclists that a pneumatic tyre has an inbuilt tendency to run straight; it possesses a self-centring action, due in the main to the reaction between the road surface and the resilient tread, which tends to turn the wheel in the direction of any side-force applied to it. Thus, if the wheel happens to be turned while in the air after negotiating a severe bump, so that the tyre lands at an angle, the self-aligning force generated will move the wheel back into line, so fast, perhaps, that it overshoots and turns in the opposite direction.

Meanwhile, this oscillation of the wheel about the column axis sets up gyroscopic precessional forces (as in the case of the hoop) which tend to make the whole wheel and fork oscillate from side to side, and if the two sets of forces act in harmony the action will build up until a full-lock wobble is in progress. That is one reason why a machine which steers well with one size of tyre may be inclined to "shake its head" with another size, even though the diameters (and thus the rake and trail also) are identical; the geometry is the same, but the gyroscopic mass and the self-aligning force of the tyre have been altered.

Pendulum Effect

Other things come into it, of course. One is the "pendulum effect" of the whole front assembly, which tends to resist rapid turning of the bars or conversely wants to maintain a turn once it has started. Another is the rigidity or otherwise of the rest of the main frame; if this can bend or twist, it must deflect the rear wheel out of line and thus cause it to steer the rear end. This may only cause the tail to wag, but it may equally well accentuate any defects at the front should resonance occur between the disturbances at both ends, and the steering system may be blamed for faults which really lie elsewhere.

One effect of rake is to lower the whole front of the machine when the wheel is turned to either side. This can be appreciated by visualizing a system brought to an extreme, with the head so far back that it is almost horizontal: obviously, if the bars are turned the wheel will lean over and the axle will drop in relation to the ground. The same thing occurs with a normal amount of rake (though, of course, to a smaller extent) and its effect in practice is to cause the steering to turn in the direction in which the machine is trying to fall, provided there is some trail as well. It can be demonstrated merely by tilting a stationary bicycle to one side, whereupon the front wheel will promptly turn in the same direction; if the machine were moving, it would immediately run to that side and centrifugal force would bring it upright again.

This is the main factor in achieving stability at low speeds when the gyroscopic effects of the wheel are small. A nice balance between the head angle and the trail must be achieved if good steering at low speeds is the primary aim; too much rake in particular causes the model to fall inwards too far, and reverse correction may have to be applied to the bars.

The effect of trail is to move the contact-point of the tyre off the centre line and away from the direction of turn. Should the wheel be deflected whilst the machine is vertical and travelling straight ahead, the rolling resistance of the tyre, combined with the fact that it is now at a slight angle to the mean line of travel, will try to pull the wheel back into line in just the same way as the castor-wheels of an armchair move round until they lie straight behind the pivots.

The effect of trail, then, is to make the machine run straight whilst it is vertical—

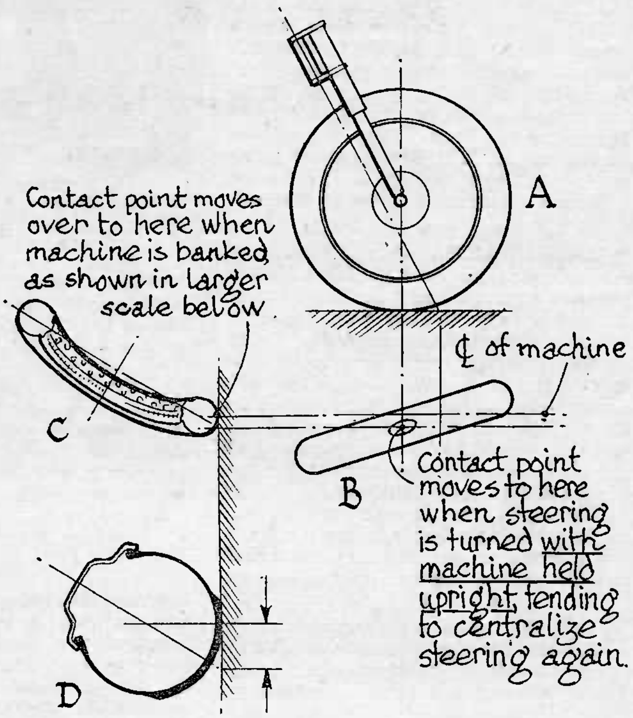

Fig. 2. The effects of trail and tyre section: A is the side elevation of a steering system, B its plan view when the handlebars are turned but the machine remains upright, C and D are sections through the tyre when banked.

but conversely, when it is banked over, trail tends to turn the wheel into the direction of lean and operates as a corrective influence in conjunction with rake.

Trail, however, is really a theoretical conception of the distance between the tyre contact point and the column axis at ground level, assuming a rigid tyre of zero width. In practice, the tyre has a finite area of contact, not merely a point, and it also has a cross-section which is approximately circular. The effect of flattening the tread at ground contact is to shorten the effective trail (hence the need to maintain tyres at their correct inflation pressures) and the effect of the circular section is to reduce the distance by which the theoretical point of contact moves out of line when the machine is in a banked turn. That is because the tyre acts, as it were, as a roller between rim and road, and the amount of displacement is reduced, as shown in Fig. 2.

If instead of being circular the tyre had a section with a flat tread, as employed on cars, the virtual point of contact might actually move to the inside of the curve, and would attempt to turn the wheel still farther inwards, i.e., in the wrong direction. This variety of tyre usually possesses a large self-aligning force, which would then take charge and pull the wheel back into line, possibly so quickly that it would swing through to the other side and commence to oscillate. This, incidentally, is a problem encountered in tricycle-type aeroplane landing gear, in which on at least one occasion the "shimmying" so initiated ended in the total destruction of the aircraft. Another disadvantage of very-big-section tyres is that when an object such as a large stone is struck a glancing blow the disturbing effect on the wheel is much greater than with a narrow tyre, hence the use of small-section front covers on trials models.

Of course, this movement of the contact-point out of the centre plane occurs on the rear wheel also and to some extent cancels out the effects at the front. In fact, the relation between the two tyre sizes is quite important, and explains why some machines handle better if front and rear tyres are "odd" than if they are of similar section.

At speed, the conditions are the same when travelling upright in a straight line, except that gyroscopic forces become much more important since they increase with the square of the velocity of the rim. At very high speeds they may even become an embarrassment—when, for instance, traversing a series of right and left bends. It is in these circumstances that lightweight tyres and aluminium rims pay a dividend in increased ease of banking the model from one side to the other.

TO BE CONTINUED