MOTORCYCLE ENGINEERING—2

Steering Geometry

by PHIL ("SLIDE RULE") IRVING

Continuing a review of the general stability problems of the two-wheeler and their effect upon the basic theory of "front end" design

In our last week's issue Phil Irving began his discussion on this vital aspect of motorcycle design and in these pages he completes this particular section of our new series.

WHEN rounding a curve at a steady speed, the model is banked inwards to an angle such that the centrifugal force, acting outwards through the centre of gravity of the whole equipage, is exactly balanced by the tendency to fall inwards. When this condition is reached—which is, of course, slightly later than the transitional period of change from straight travelling to cornering—a condition of equilibrium is again established.

The resultant of the two forces now acts substantially in the plane of the frame, as shown in Fig. 3, and conditions are roughly similar to straight travelling, except that the ground contact-points have moved round the tyres by an amount depending upon the angle of bank and the tyre sections. The resultant force must lie in the plane containing these two points and the centre of gravity.

Apart from this small deviation, the resultant force, although greater than the gravitational force by as much as 40% at maximum bank, has little effect except to increase all the loadings by the same percentage. If, however, either wheel passes over a bump, the machine is subjected to an impulsive force which is substantially vertical and thus at an angle to the centre-plane. One effect of this is a tendency to turn the front wheel farther into the corner, which has to be resisted by the rider through the medium of the handlebars. It will also bend or twist the whole machine to an extent which depends upon the rigidity of its construction and the disposition of the major components. The second point must be mentioned in any discussion on steering, because whatever geometry is employed on paper its virtue can be entirely destroyed by secondary causes of this nature.

To get down to some solid figures, the experience of years has shown that a rake of between 25° and 30° from the vertical will give good results combined with a trail in the region of 3 in. Some authorities claim that the precise angle is not very important, others state very emphatically that it is critical to within half a degree.

Such differences of opinion are hard to explain but may be accounted for, at least in part, by fundamental constructional differences in the various types of machines tested. However, rake is a thing which is difficult to vary during production and it certainly pays to experiment with differing angles at the experimental stage, using if possible a variety of test personnel, to establish the figure which gives the nicest handling under the conditions for which the particular model is intended.

Fork Trail

Trail does appear to be of somewhat less importance. It can be varied quite widely without any very serious ill-effects, but any alteration is bound to make a difference to the "feel" of the machine. Generally speaking, a trail of 3 to 4 in. will give very good high-speed steering, with some heaviness on corners, while a figure around 2½ in. will give lighter cornering but less feeling of solidity at high speeds.

So far, we have been talking only about conditions as they exist in normal riding—that is to say at moderate speeds in calm atmospheres and on good surfaces—and it is quite certain that if the handling is bad then it will be even worse under less favourable circumstances. If, for instance, a machine is pushed to its limit on a corner, which may be done deliberately under racing conditions and inadvertently (one hopes) in touring, questions of roadholding and tyre adhesion may take precedence over the accuracy of the steering.

Roadholding in this context means the closeness or otherwise with which the tyres remain in continuous contact with the road. Should either wheel aviate for any appreciable period, only the gyroscopic forces are available and they can, in fact, operate to the rider's disadvantage. If, during a long jump over a humpbacked bridge, the bars are turned to the left in anticipation of a turn which immediately follows, gyroscopic precession of the front wheel will cause the model to lean over to the *right*, so that when it lands it is banked the wrong way and the only method the rider has of saving

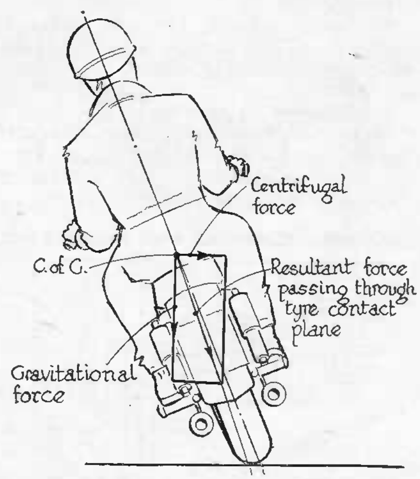


Fig. 3. *Showing how the centrifugal force and gravitational force (weight) of the complete machine can be combined into one larger force passing through the points of contact with the road.*

his skin is to alter course, then straighten up and bank over for the left turn—always supposing there is room to execute this tricky operation.

The lighter the wheel is in relation to the total weight, the less this effect will be, but it is always present to some extent and the only way to avoid it is never to turn the bars when the front wheel is off the ground.

In the days of rigid frames, now almost extinct except on speedway machines, it was very difficult to maintain rear tyre contact on anything but a billiard-table surface, and the back end was always liable to " step out " on a corner and might even slide right round. Even with a well-sprung rear wheel this can still happen, partly because no suspension ever devised could possibly absorb every bump completely, and partly because the sprung motion which takes place in the plane of the frame cannot absorb any of the vertical components of the road shocks received when the machine is inclined.

When, in consequence of this, the tyre is bumped clear of the surface, centrifugal force carries the rear wheel outwards (Fig. 4). If the rider grimly maintains the bars in a fixed position the whole machine, including the front wheel, will be at a slight angle to its correct line of travel and will try to head in towards the inner side of the corner; but if he relaxes sufficiently to allow the front wheel to steer itself, that wheel will maintain its true path, although almost immediately afterwards correction may have to be applied to bring the model as a whole back on course.

Tyre adhesion is a different matter from roadholding. It is a measure of the amount of grip existing between the tread and the road, and depends upon the type, character and dryness of the road surface, the composition of the rubber in the tread and, to some degree, the tread pattern. This is far too long a subject to deal with here; it is sufficient to say that as soon as the force available from adhesion becomes insufficient for steering purposes on either wheel, maintaining balance becomes a matter purely of riding skill.

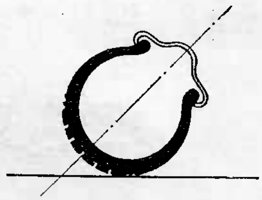
For racing under good conditions, where long sweeping curves must be taken at full speed, it is desirable to distribute the weight and select tyre sizes and patterns so that both wheels will start to slide at the same time, which is the reason why modern racing machines have their power units placed well forward. The main snag of this arrangement is that, if the road surface suddenly changes its character—for instance, through an unexpected patch of oil or gravel on a bend—the model may go down flat on its side before the rider can do anything about it, whereas on a mount which handled less well the cornering speed would be slower and the front wheel might have just enough adhesion left to permit the necessary correction to be applied as the rear wheel slid outwards.

It is worth noting at this juncture that a tyre loses its adhesion and commences to slide sideways or slip circumferentially whenever the vector sum of *all* the forces acting parallel to the road surface exceeds the frictional grip of the tread. By " vector sum " is meant the resultant of the circumferential and lateral forces, determined graphically by representing each force as a line in the direction of the force and proportional in length to its value, as is done in Fig. 3, to show the resultant of centrifugal and gravitational forces.

As soon as the tyre commences to slide in any one direction, it will lose its directional stability in *all* directions and incidentally entirely loses its self-aligning property. Thus, if a corner is being taken near the limit of safe speed, quite a light application of the rear brake will cause the tyre to lose adhesion and once it starts to slide it will go anywhere. In a sense, a similar thing happens at the front too, but owing to a phenomenon known as " weight transference "—which will be dealt with in a later article in this series—the initiation of a slide by braking on a corner is more likely to happen at the rear than at the front. Rear " break-away " can also be caused by applying too much power on a corner, particularly when accelerating from a low speed with the model banked hard over, but its onset can be controlled to some extent by correct design of the tread. Some years ago racing tyres had a fairly narrow band of studs, with several continuous side-ribs extending well up the walls and under the conditions described only some of these ribs and not the studs were in proper contact with the ground and the tyre would consequently spin relatively easily when power was applied. As soon as this happened, the wheel promptly slid outwards, demanding instant corrective action by the pilot to hold the model up; increasing the width of the studded area to bring it much farther round the walls did much to improve cornering safety, particularly on acute corners.

However, enough has been said by now to indicate that to obtain good handling under all conditions is by no means a simple problem; nevertheless, the number of corrections which may have to be made to an experimental model will be reduced if all the points discussed are borne in mind.

When laying-out the frame and fork design, it is best to draw it in the position of normal load and to fix the rake and trail as they then exist. These then become datum figures but, of course, they must alter considerably as the attitude of the frame in relation to the ground alters with deflections of the springing at either end.



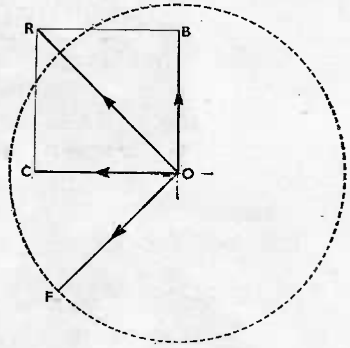


Fig. 5.
OC=*Centrifugal force (smaller than OF);*
OB=*Braking force (also smaller than OF);*
OR=*Resultant of OC—OB (larger than OF);*
OF=*Frictional force of tread.*

The type and detail design of the front fork and suspension will be discussed in the next article of this series to appear in our issue dated September 17.

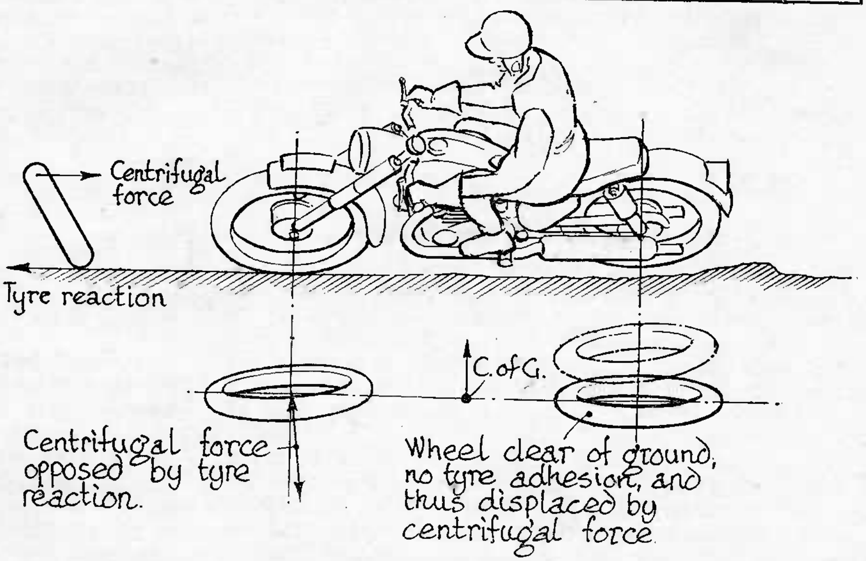


Fig. 4. *When cornering on a rough surface, the rear wheel is likely to " step out " after being thrown clear by a bump.*