MOTORCYCLE ENGINEERING—9

WHAT GIVES?

Part One — The designer's choice of springing and damping media

by PHIL IRVING

ANY suspension system for a road vehicle must possess two basic properties—elasticity to absorb bumps and damping to prevent the build-up of undesirable oscillations. The necessity for the first-named is evident, but the second needs a little explanation.

Briefly, if a body suspended by a spring in such a way that there is no friction present, is displaced and then released, it will oscillate or vibrate for a considerable time. The amplitude or total length of movement at the commencement will be just twice that of the original displacement, but will eventually die away to zero, partly because of air-friction and partly through energy-loss in the spring material. Acting together, these damp out the vibration and dissipate the stored energy in the form of heat.

In practice a vehicle with undamped springing will bounce up and down several times after striking a single bump, and if it traverses a succession of bumps at a speed corresponding to the natural frequency of vibration of the main mass of the vehicle on the springs, the oscillations will build up until they become dangerously violent. If, however, some means of absorbing energy is incorporated—such as by friction-pads or by forcing oil through small orifices—free vibrations will be damped out rapidly and forced vibrations will be kept within tolerable bounds.

Undamped Bumps

Damping also works to prevent "overthrow" of the wheels over bumps. When a bump is struck at high speed, the wheel attains a considerable upward velocity and may leave the ground at (or even before) the crest of the bump because the momentum of the wheel over-compresses the spring. An additional damping force will reduce this overthrowing tendency by absorbing some energy which would otherwise be applied to the spring.

If a model "takes off" over a bridge or meets a sudden drop in height of the surface, the suspension will momentarily have little or no weight on it, so that on landing the springs are partly or fully extended. As the weight comes down hard, the springs will be compressed beyond their normal-load position and immediately afterwards will throw back violently unless damping is provided on the rebound stroke.

Some makers, in fact, consider that rebound damping is all that is necessary, and that any damping on the bump stroke only results in a harder ride. Whilst that view is true to some extent, it is possible to meet conditions—on corrugations, for instance—where the wheel is repeatedly jolted upwards and does not have time to recover from one bump against the rebound damping before the next bump pushes it up still farther, so the springs become over-compressed and the ride remains uncomfortable as long as the conditions continue.

However, this is a point which will be discussed in a later article. The salient fact is that no suspension system can function satisfactorily without some form of damping, which may or may not be inherent in the springs themselves.

As to these components, there are three main materials employed in the manufacture of elastic devices for suspension systems in general. These are steel, rubber and air. All have been tried in one way or another for both the front and the rear springing of motorcycles. Steel is by far the most popular, but as the two non-ferrous materials possess qualities which are peculiar to themselves, it may be worth while to examine them first before turning attention to the more usual material.

Air can operate as a spring only when compressed in an airtight container of variable volume. The variation may be achieved by a cylinder-and-piston arrangement, in which the piston is either a plunger or a rising column of oil. Alternatively, the air-chamber may be closed by a flexible diaphragm which is itself acted upon by oil under pressure transmitted from the suspension mechanism, on the lines of the system used in Citroen cars.

In whatever way it is compressed, air has the property of providing a progressive spring-rate, this being one of its outstanding properties. The term "rate" as applied to a spring means the amount of load, measured in pounds, which is required to compress the spring one inch—or, in the case of air, to compress the device in which the air is contained.

A normal parallel-wound helical coil spring has a constant rate; that is to say, if it takes 100 lb. to compress it one inch, another 100 lb. will compress it a further inch, and so on until it becomes coil-bound. However, with air (taking as an example a simple piston-and-cylinder arrangement) the rate rises continuously from the start of compression until it reaches an infinitely high value at the end of the stroke. Furthermore, as air cannot be compressed into no space at all, mechanical bottoming is impossible, though the final pressures generated might be hundreds of pounds to the square inch.

Maintaining a perfect air-seal indefinitely with a reciprocating piston would be virtually impossible, but if the air is compressed by a rising column of oil, as in the Dowty oleo-pneumatic strut utilized on Velocette racing models, or the Dowty fork, direct leakage of air is prevented and hydraulic damping can be provided at the same time by making the oil pass through controllable orifices on its way to and from the air-chamber. Sealing glands are still necessary to retain the oil, and entirely eliminating leakage past these, though not impossible, is a difficult problem, partly because of the inevitably gritty environment and partly because the pressures developed can reach very high values.

Consequently oleo-pneumatic struts are both expensive and heavy and are not at present employed on motorcycles. The fact remains that they provide suspension characteristics which cannot be exactly duplicated by any coil-spring system. Moreover, they are easily adjusted to sustain various loads, or to alter the quality of the suspension to suit different road conditions, merely by the application of a tyre-pump.

On the other hand, when air is compressed it becomes hot and some of the heat of compression generated on each bump stroke is transmitted to the cylinder, so that under continuous working the whole unit rises in temperature and consequently in pressure, thereby jacking up the rear end a little (in the case of rear suspension) and increasing the hardness of the ride. This effect can be quite noticeable and was, in fact, a matter which had to be allowed for in setting the air-pressure when oleo-pneumatic legs were employed for racing.

Despite its disadvantages, however, air-springing might well merit further attention today, especially on machines with an overhung rear axle carried, scooter-style, on a single arm. As only one unit would be required, the additional cost would not be excessive and the problem of obtaining equal pressures in a pair of units without an undesirable balance pipe would be non-existent.

Historically-minded students of design may recollect that a single air-spring was fitted to both the front and the rear suspension of the A.S.L., *circa* 1910. The air was retained by an ingenious rolling sleeve which, however, precluded full use of the progressive-rate feature, as, being made of soft rubber devoid of reinforcement, it would have been unable to withstand the high peak pressures developed at full bump.

Rubber has several properties which make it an attractive springing medium. It can be used in tension or compression. It can be moulded into almost any shape. It can be bonded to metal parts so firmly that the rubber will fail before the bond gives way. Finally, by suitably varying the "mix" or by the addition of fillers it can be endowed with a great amount of inherent damping capacity through the absorption of energy by hysteresis (internal friction). This action generates heat right in the heart of the rubber, and if too much inherent damping is provided, extremely severe conditions may cause softening or even destruction of the material; on that account some additional form of damping is usually necessary.

One disadvantage of rubber is that the working range is rather small and therefore it is necessary to multiply the deflection by some system of leverage. A simple way of achieving this is to use a pair of blocks, one above and one below the pivot-bearing of a swinging fork, and compress them between abutments on the frame and the forks; but this introduces heavy local loads which do not exist when the springs are arranged in a direct line between the axle and the weight to be supported. A rather interesting construction, using conical rubbers in torsion mounted coaxially with the pivot, was developed some years ago by Spencer-Moulton, but here again heavy local loads were generated and, owing to the low rate of the torsion-rubbers, additional rubber stops were necessary to limit the travel in both directions.

Rubber has been used on front forks, in a very simple way, merely by hooking a number of rubber bands over bobbins, a progressive rate being obtained by making some of the bands slack in the normal position so that they only came into action towards the end of the bump stroke.

In the Greeves front fork, bonded rubber bushes are used at the pivots of the leading-link forks to act both as oscillating bearings and as springs, the rubber in this instance being in shear, not torsion. As the links are joined by a loop-tube as well as by the axle, the assembly is stiff enough laterally to provide excellent steering for solo work. Hydraulic dampers concealed within the main fork tubes are required, because the small amount of rubber employed does not provide enough inherent damping for the arduous conditions in which these models usually perform.

Steel can be utilized in three forms—laminated or leaf springs, torsion bars or coil springs. All have been used at one time or another, either for front or rear suspension.

Three Ways with Steel

Leaf springs are not very suitable for motorcycles because the only shape convenient to install is the quarter-elliptic, which, being overhung, creates heavy local loads in the mounting brackets with consequent liability to fatigue-failure. In any case, the leaf spring is much heavier than an equivalent coil giving the same suspension rate. Inter-leaf friction supplies a degree of inbuilt damping which is beneficial, but difficult to control—in fact, at times leaf springs may become almost solid.

Torsion bars are entirely the reverse. They possess virtually no self-damping, but are difficult to employ because to avoid overstressing the material the bars must be of considerable length, a fact which precludes their being mounted transversely. Instead, they must be installed parallel to the frame and then connected to the moving components by a link-and-lever system, all of which introduces extra weight and complication. The inboard anchorages are again a long way from the point of application of the major loads, and about the only thing that can be said in their favour for motorcycle work is that adjustment for height (though not for rate) can easily be made by turning the anchorages a few degrees in the desired direction.

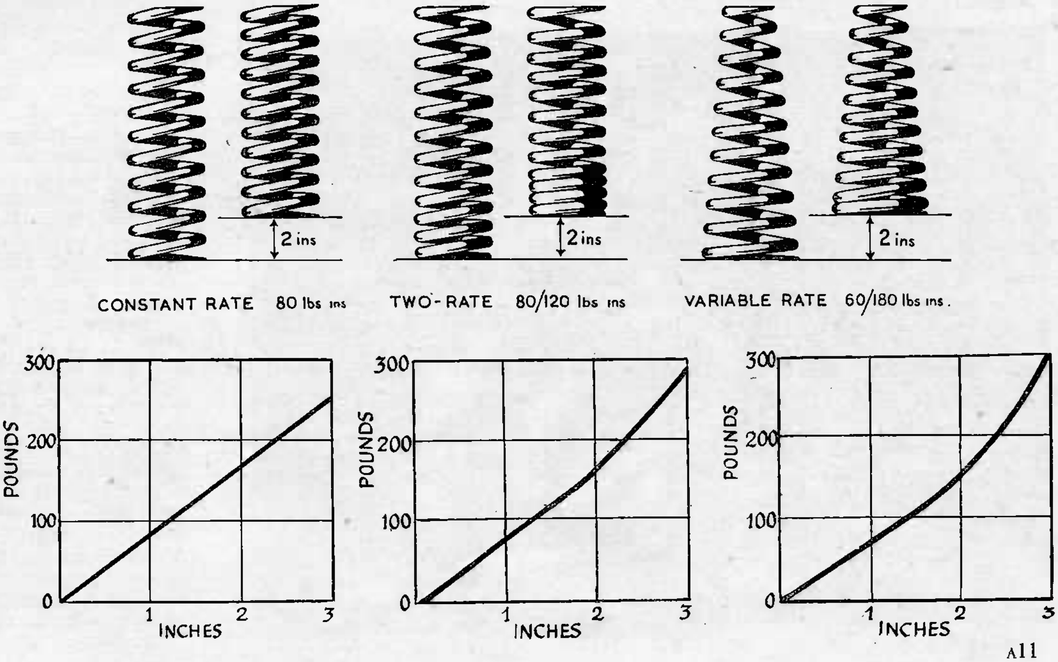
The simplest, lightest and most convenient form is undoubtedly the coil spring, which can provide enough travel to enable suspension units to be mounted almost in line with the rear axle and then take the most direct route towards the supported weight. The ordinary spring, with coils of constant diameter and pitch, has a constant rate, but by the simple expedient of winding the coils with two or even three pitches, two-rate or triple-rate springs can be obtained.

A multi-pitch spring has a low initial rate during which *all* the coils are closing up until those with the closest pitch commence to touch or "come solid." After that point there are fewer active coils to absorb further motion and the rate becomes higher because for any given outside diameter and gauge of wire the rate is directly proportional to the number of active coils. The change in strength of a triple-rate spring occurs twice and this type begins to furnish an approximation to the characteristics of an air-spring.

Another way to obtain a variable rate is to wind the spring to conical or barrel shape. In either form, the coils with the largest diameter are deflected farther for the same load than are the smaller ones; consequently they close up first, leaving fewer coils of progressively smaller diameter (and therefore greater stiffness) to take up the remainder of the travel. Barrel springs were almost universal in girder forks. This was due partly to the lack of sufficient space at the upper end to employ a parallel spring of equal overall stiffness, but in view of the short available movement a variable rate was almost essential in order to obtain a comfortable ride without undue bottoming.

This is, in fact, the prime advantage of a variable rate. The suspension is relatively soft over the initial part of its movement, thus giving good "cobblestoning," or comfort on short, small irregularities, whereas the increasing resistance at larger travels tends to prevent bottoming over severe bumps. It also has an additional advantage when compensation for varying loads is being provided, but the additional cost of manufacture is not always considered to be justified.

(To be continued)



CONSTANT RATE 80 lbs ins

TWO-RATE 80/120 lbs ins

VARIABLE RATE 60/180 lbs ins.

What happens when three types of spring are compressed. Change of rate is indicated in the graph below each example. The spring of equal pitch has no change of rate. The rate of the two-rate spring increases when its close-pitch coils have become "solid." Closure of coils in the variable-rate spring, beginning with those of the greatest diameter, gives a progressive increase of rate.