PATENT SPECIFICATION

Inventor: EDMUND RAMSAY WIGAN.

665,741

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PROVISIONAL SPECIFICATION

Improvements in or relating to Shock Absorbing Springs

I, THE MINISTER OF SUPPLY, of Shell Mex House, London, W.C.2, do hereby declare the nature of this invention to be as follows:—

The provisional and complete specifications of patent application No. 32770/45 describe springs of sinusoidal form, hereinafter referred to as "sine springs," which can be so mounted that positive, zero or negative stiffness can be obtained as may be desired. According to the present invention one or more sine springs are combined with one or more springs of the conventional type in such a way that stiffness/displacement characteristics are obtained which make the assembly suitable for giving isolation from mechanical shock. For instance if a conventional spring has a stiffness of 200 lbs/inch, this stiffness may be reduced to 4lbs/inch by coupling to the conventional spring a sine-spring of stiffness—196 lbs/inch. But the negative stiffness of a sine-spring is dependent on the displacement of the spring from its position of symmetry, and consequently the net stiffness of the spring combination suggested above will vary as the linked springs are deflected. The sine-spring may therefore be adjusted so that the variation of stiffness is (within certain limits of deflection) made as small as possible, or alternatively is made to follow a prescribed law either of increase or decrease with increase of deflection.

Fig. 1 of the accompanying drawing shows diagrammatically a sine-spring. I have found that the curve relating stiffness to displacement of a sine-spring is in general **U** or **∩** -shaped, depending upon the sign of the angles θ_1 and θ_2 shown in figure 1 of the accompanying drawing. If θ_1 and θ_2 are both positive (as shown in Fig. 1), a force applied to the centre point C of the blade will result in a deflection which, while increasing as the force increases, will not be proportional to the force; as the force becomes larger the incremental deflection resulting from a small increase in force become smaller and smaller. Conversely if θ_1 and θ_2 are negative, i.e. the angle θ_1 is increased above the centre line and θ_2 below the centre line of Fig. 1, the opposite effect occurs: as the force grows larger the incremental deflections due to a small increase in applied force become larger and larger. Clearly in the region of $\theta_1 = \theta_2 \div$ zero the curve must take intermediate shapes: some of these are found to show remarkable constancy of stiffness within a certain range of displacement about the central position of the sine-spring. In what follows a spring will be described as having "pure" stiffness if the stiffness is not dependent upon deflection.

In one application of the invention a spring assembly designed to support a weight, for example a cantilever spring supporting the saddle of a motor cycle, is coupled to a "pure" negative stiffness spring of the type just described so as to improve the insulation from road shocks. The cantilever spring might, for instance, have a stiffness of 200 lbs/inch and the sine-spring a negative stiffess of 196 lbs/inch. If the weight of the rider were applied to this combination, the linked springs would be pushed at once to their limit-stops since the effective total stiffness would be only 4 lbs/inch. If however the two springs are not coupled together until the rider is in position in the saddle the system is stable. For if the cantilever spring, with the rider in the saddle, comes to rest in a position of equilibrium, then this equilibrium will not be disturbed if the negative stiffness sine-spring, also in a state of equilibrium, is then coupled to the cantilever spring. There is always such a position of equilibrium, in the case of the sine-spring, near to the position of symmetry if $\theta_1 \doteqdot \theta_2$. The position is easily recognised when the stiffness is negative, since the sine-spring blade ,when free, tends to fly away (upwards or downwards in Fig. 1) from this position.

If the saddle spring is, in this sequence, coupled to the compensating negative stiffness sine-spring, the weight of the rider is supported by the cantilever-spring when the vehicle is at rest. If the wheels pass over (say) a 1 inch bump in the road the wheels and frame will rise by about an inch, but the saddle with the weight of the rider in it will move only very slightly, for the 1 inch rise causes a force of only 4 lbs to be developed on the body of the rider (say 120 lbs) resulting in an upward acceleration of only g/30, thus giving very effective isolation from the shock due to the bump.

In order to achieve these objects means must be provided which allows for:—

(a) the separation of cantilever and sine-spring when the rider mounts;

(b) the simultaneous locking of the sine-spring in its position of equilibrium;

(c) the re-linking of cantilever and sine-spring after the load is applied to the former (both being in equilibrium when re-linked);

(d) the release of the sine-spring clamp after the re-linking.

Although the example of a cantilever motor-cycle saddle support has been described, the general principle is applicable wherever a massive body has to be isolated from shock. For example, the axles of the road wheels of a car may be provided with cantilever or semi-elliptic springs in combination with sine-springs. Such a vehicle will ride with the degree of shock isolation common to standard springing methods when the sine-springs are disconnected. But it will ride almost perfectly when they are connected.

The principle described may also be applied to any method of packing goods for transit designed to reduce shock or to methods of isolating delicate apparatus from floor vibration.

Although a single sine-spring has been mentioned in the example used for illustration above, combination of two or more sine-springs may be used in place of the single spring. Such combinations may consist of, for instance, one sine-spring with a U-shaped stiffness/displacement curve and one with a ∩-shaped stiffness/displacement curve. By proper choice of the angles θ_1 and θ_2 and the dimensions A, D, and l in Fig. 1 these two curves may be closely matched so as to result in a compound sine-spring in which the stiffness is nearly "pure" over a range of deflection which is wider than can be achieved by either spring alone. In such compound springs each sine-spring experiences the same deflection.

However "tandem" constructions may instead be used in which each sine-spring experiences the same force: the total deflections of such a compound system is the sum of the deflections of the component sine-springs under the action of this force By suitable choice of angles θ_1 and θ_2 of the two sine-springs, they may be given force/displacement characteristics such as (a) and (b) in Fig. 2 of the accompanying drawing. These are substantially identical in shape except that (b) is displaced from (a) by a constant force F_o. The sum of these two curves shown at (c) has clearly a greater range of linearity than (a) or (b). If now the central section of (a) and (b) is made vertical (i.e. zero stiffness), by choice of the angles θ_1 and θ_2 of the springs, the tandem combination of these two sine-springs alone will support a load approximately equal to $F_o/_2$ with almost perfect isolation from external shock.

Similar arrangements may be made to extend the range of linearity of sine-springs developing negative stiffness.

Dated the 9th day of November, 1948.
S. W. SLAUGHTER.

COMPLETE SPECIFICATION

Improvements in or relating to Shock Absorbing Springs

I, The Minister of Supply, of Shell Mex House, London, W.C.2, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to shock absorbing springs and involves the use of springs of sinusoidal form hereinafter referred to as sine springs) of the character described in British Patent Specification 617,076.

According to the invention a spring assembly for the absorption or isolation of shock comprises at least one sine spring arranged for negative stiffness operation and combined for movement in unison with at least one spring of positive stiffness, means being provided for bringing the sine spring into equilibrium when the spring assembly is in an operative or loaded condition. For example, if a spring has a positive stiffness of 200 lbs./inch, this stiffness may be reduced to 4 lbs./inch by coupling to the conventional spring a sine spring of stiffness—196 lbs./inch. But the negative stiffness of a sine-spring is dependent on the displacement of the spring from its position of symmetry, and consequently the nett stiffness of the spring combination suggested above will vary as the linked springs are deflected. The sine-spring may therefore be adjusted so that the variation of stiffness is (within certain limits of deflection) made as small as possible, or alternatively is made to follow a prescribed law either of increase or decrease with increase of deflection. In what follows a spring will be described as having " pure " stiffness if the stiffness is not dependent upon deflection, that is to say that the ratio of the force to the resulting displacement is constant, independent of the magnitude of the force.

In one application of the invention a spring assembly designed to support a weight, for example a cantilever spring supporting the saddle of a motor cycle, is coupled to a " pure " negative stiffness spring of the type just described so as to improve the insulation from road shocks. The cantilever spring might, for instance, have a stiffness of 200 lbs./inch and the sine-spring a negative stiffness of 196 lbs./inch. If the weight of the rider were applied to this combination, the linked springs would be pushed at once to their limit-stops since the effective total stiffness would be only 4 lbs./inch. If however the two springs are not coupled together until the rider is in position in the saddle the system is stable. For if the cantilever spring, with the rider in the saddle, comes to rest in a position of equilibrium, then this equilibrium will not be disturbed if the negative stiffness sine spring, also in a state of equilibrium, is then coupled to the cantilever spring. There is always such a position of equilibrium, in the case of the sine-spring, near to the position of symmetry if $\theta_1=\theta_2$ (in Figure 1 of the drawing accompanying the Provisional Specification). The position is easily recognised when the stiffness is negative, since the sine-spring blade, when free, tends to fly away from this position.

If the saddle spring is, in this sequence, coupled to the compensating negative stiffness sine-spring, the weight of the rider is supported by the cantilever-spring when the vehicle is at rest. If the wheels pass over (say) a 1 inch bump in the road the wheels and frame will rise by about an inch, but the saddle with the weight of the rider in it will move only very slightly, for the 1 inch rise causes a force of only 4 lbs. to be developed on the body of the rider (say 120 lbs.) resulting in an upward acceleration of only g/30, thus giving very effective isolation from the shock due to the bump.

Reference will now be made to Figures 1 and 2 of the accompanying drawings which illustrate two applications of the invention.

Figure 1 shows an arrangement of shock absorption apparatus according to the invention suitable for the suspension of a motor cycle saddle. The arrangement comprises a cantilever spring 1 supporting a saddle (not shown) and connected by an adjustable coupling device in the form of a shackle to a sine spring 2. Both springs are mounted fore and aft in the frame 3 of the vehicle, the sine spring 2 being clamped in two adjustable anchorages 4, 5 which are adjusted so that the stiffness of the sine spring 2 very nearly cancels the stiffness of the cantilever 1 and is finally locked by screws 6, 7. The shackle is mounted underneath the saddle in an accessible position and consists of two threaded members 8, 9 engaging with a nut member 10. The threads on the members 8, 9 are both right-handed but of different pitch. If, for example, the member 9 has 6 threads per inch and the member 8 has 8 threads per inch, rotation of the nut member 10 by one turn clockwise (viewed from below), moves the member 10 1/6th inch nearer to the cantilever 1 and rides 1/8 inch up the thread of member 8, thus shortening the shackle by 1/24 inch. Other arrangements of threads may be used as desired.

The procedure to be followed when adjusting the shackle initially or when the load is altered is as follows: with the load in place the shackle is adjusted in length until the sine spring 2 lies with its centre point on the line of centres of its clamps. The sine spring then carries no load but the cantilever 1 takes the full load by deflecting.

The adjustment of length of the shackle needed is very small. Suppose, for example, a load of 100 lbs. deflects the cantilever (acting alone) by ½ inch. The adjustment in length of shackle for the difference between a 100 lb. and 200 lb. rider is ½ inch. The adjustment required to take care of the variation of a single rider due to the weight of extra clothing, overcoat, etc. (say 5 lbs. variation) would be only 1/10 inch. A differential thread with a capacity of ¼ inch total adjustment should suffice for day to day adjustment, the connection of the shackle with the springs 1 and 2 being made adjustable for major alterations and preset to suit the average weight of the rider.

Figure 2 shows diagrammatically the arrangement of a system suitable for a larger load or for a four-wheeled vehicle. The sine spring 2*a* is in quadruplicate (S_1—S_4) and is anchored at 4*a* and 5*a* to the frame 3*a* of the vehicle. Its centre 11 is connected to the centre-piece 12 of a semi-elliptic spring 1*a* by an hydraulic adjustable coupling device or shackle comprising a cylinder member 13 attached to the sine spring 2*a* and a piston member 14 attached to the centre-piece 12 of the spring 1*a*. Fluid is fed into the top of the cylinder of the member 13 through a pipe 15 via a stop-cock 16. The shackle is adjusted by admitting or exhausting fluid from the cylinder until the sine spring lies in its position of symmetry with the load on the vehicle, when the stop-cock is closed. The members 13 and 14 are then locked together and act in the same way as the assembly described with reference to Figure 1.

It is to be noted that in a spring assembly according to the invention no danger to the load or passenger arises from a fracture of a sine-spring since the load is carried by the spring member or members of positive stiffness. If the sine spring or shackle fails the shock absorbing feature only of the assembly is impaired.

To add negative stiffness to the sine spring without increasing its thickness (which would lead to increased tensile stress) the blade may be made wider. If this does not give sufficient negative stiffness the number of blades may be increased as shown in Figure 2. The negative stiffness then increases in direct proportion to the number of blades incorporated. In such assemblies it is necessary to leave a clearance between the blades at the point of anchorage, otherwise some parts of the blades may rub together when the spring is deflected.

Suitable friction linings may be applied to adjacent blade surfaces so that the deflections of the spring are damped by the relative motion of these surfaces which are pressed together by the close setting of the component sine springs.

The application of the invention is obviously not restricted to shock absorption in vehicles. It may also be applied, for example, to the packing of goods for transit or to methods of isolating delicate apparatus from floor vibration.

Reference will now be made again to Figure 1 and also to Figure 2 of the drawing accompanying the Provisional Specification.

I have found that the curve relating to stiffness to displacement of a sine-spring is in general **U**- or **∩**-shaped depending upon the sign of the angles θ_1 and θ_2. If θ_1 and θ_2 are both positive (as in Fig. 1) a force applied to the centre point C of the blade will result in a deflection which, while increasing as the force increases, will not be proportional to the force; as the force becomes larger the incremental deflection resulting from a small increase in force becomes smaller and smaller. Similarly, if θ_1 and θ_2 are negative, i.e. the angle θ_1 is increased above the centre line and θ_2 below the centre line of Fig. 1, the same effect occurs. This results in a distortion of the blade from the simple sine-like form of Fig. 1 into a more complex curve having several points of inflection. Clearly in the region of $\theta_1 = \theta_2 =$ zero the curve must take intermediate shapes: some of these are found to show remarkable constancy of stiffness within a certain range of displacement about the central position of the sine-spring.

There is always a limit to the deflection of the sine-springs—beyond this limit stiffness rapidly grows positive. By making the angles θ_1 and θ_2 of the sine-spring more positive the transition from negative to less negative stiffness is made more gentle, but at the sacrifice of uniformity of negative stiffness near the central position.

Although a single or multileaf sine-spring has been mentioned in the examples described above, combinations of two or more sine-springs may be used in place of the single spring.

Such combinations may consist of, for instance, one sine-spring with a **U**-shaped stiffness/displacement curve and one with a **∩**-shaped stiffness/displacement curve. By proper choice of the angles θ_1 and θ_2 and the dimensions A, D and l in Fig. 1 these two curves may be closely matched so as to result in a compound sine-spring in which the stiffness is nearly " pure " over a range of deflection which is wider than can be achieved by either spring above. In such compound springs each sine-spring experiences the same deflection.

However "tandem" constructions may instead be used in which each sine-spring experiences the same force: the total deflections of such a compound system is the sum of the deflections of the component sine-springs under the action of this force. By suitable choice of the angles θ_1 and θ_2 of the two sine-springs, they may be given force/displacement characteristics such as (a) and (b) in Fig. 2. These are substantially identical in shape except that (b) is displaced from

(a) by a constant force Fo. The sum of these two curves shown at (c) has clearly a greater range of linearity than (a) or (b). If now the central section of (a) and (b) is made vertical (i.e. zero stiffness), by choice of the angle θ_1 and θ_2 of the springs, the tandem combination of these two sine-springs alone will support a load approximately equal to $Fo/_2$ with almost perfect isolation from external shock.

Similar arrangements may be made to extend the range of linearity of sine-springs developing negative stiffness.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A spring assembly for the absorption or isolation of shock comprising at least one sine spring arranged for negative stiffness operation and combined for movement in unison with at least one spring of positive stiffness, means being provided for bringing the sine spring into equilibrium when the spring assembly is in an operative or loaded condition.

2. A spring assembly according to Claim 1 in which the springs of negative and positive stiffness are connected together by means of a lengthwise-adjustable coupling device.

3. A spring assembly according to Claim 2 in which the coupling device is in the form of a shackle comprising two threaded members having right-handed threads of different pitch connected by a nut member.

4. A spring assembly according to Claim 2 in which the coupling device comprises piston and cylinder members, its length being adjusted by the admission or exhaustion of fluid from the cylinder.

5. A spring assembly according to any of the preceding claims in which the positive stiffness spring is of cantilever or semi-elliptic form.

6. A spring assembly as claimed in Claim 1 and as hereinbefore described.

7. A spring assembly as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawing.

Dated this 29th day of November, 1949.

S. W. SLAUGHTER,
Agent for the Applicant.

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665,741 PROVISIONAL SPECIFICATION 1 SHEET

This Drawing is a reproduction of the Original on a reduced scale

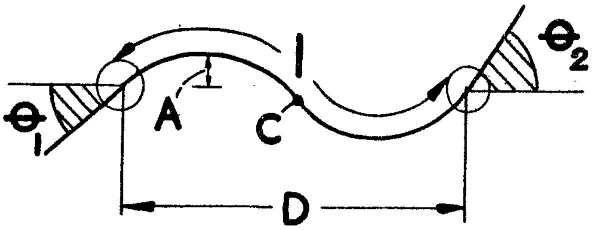

FIG. 1

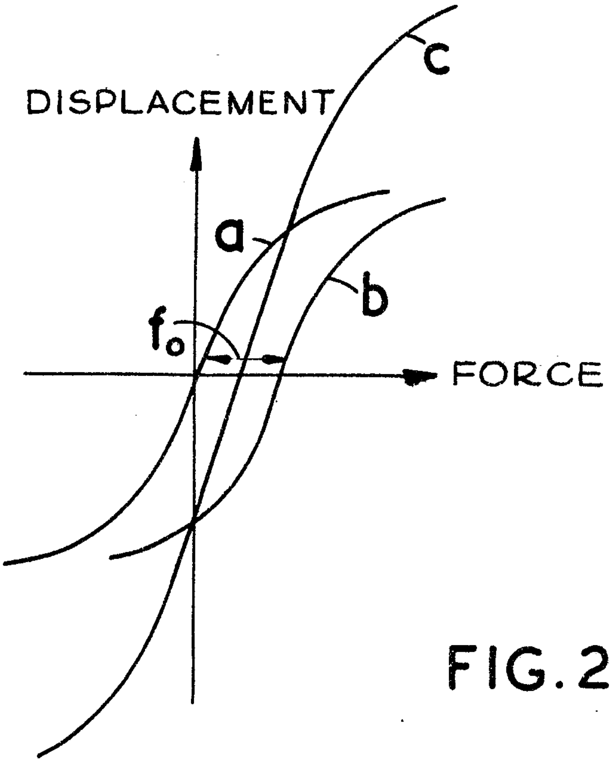

FIG. 2

H.M.S.O. (M.F.P.)

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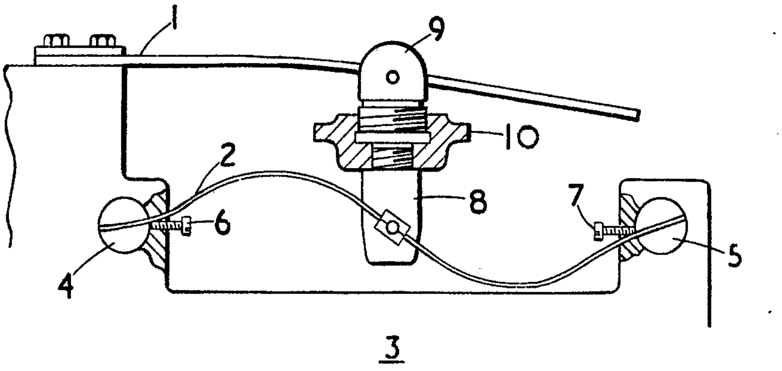

Fig. 1.

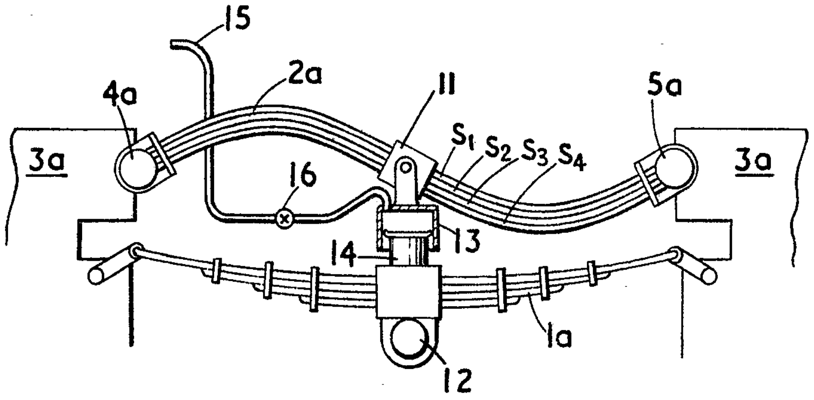

Fig. 2.