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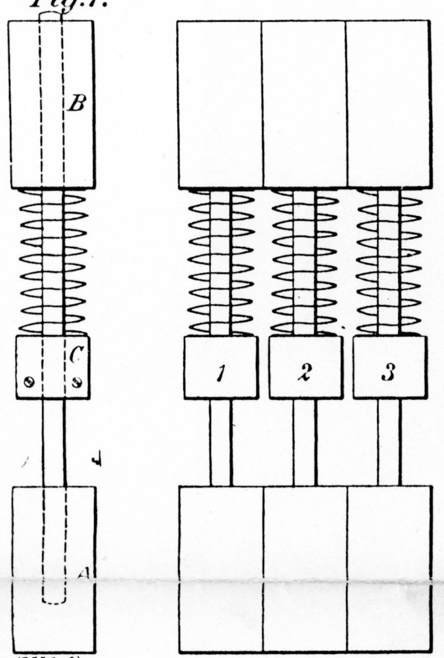
A MECHANICAL MODEL ILLUSTRATING THE BEHAVIOUR OF METALS UNDER STATIC AND ALTERNATING LOADS.

By Professor C. F. Jenkin.

In the *Philosophical Magazine* for September Mr. S. Lees describes a model to illustrate the behaviour of metal under mechanical stresses, the fundamental property of the model being that it is elastic up to a certain load, and beyond that yields partially by solid friction. This model is similar to one which the writer showed and described to a sub-committee of the Aeronautical Research Committee last June, which is based on the same fundamental property; its construction is shown in Fig. 1. It consists of three or more similar units;

Fig. 1.



(7554.A)

each unit is built up of one fixed wooden block A and two sliding wooden blocks B and C mounted on a steel rod fixed in A; B and C are connected by a spring. The sliding block B slips freely on the rod, but the block C grips it fairly tightly, the grip being adjustable. The complete model is made up of a number of these units clamped together side by side—three being the minimum number. If moderate tensile or compressive forces are applied to the model it stretches or compresses elastically, but as soon as the force on any block C exceeds the frictional force on its rod that block begins to slip. If the force is further increased the next unit begins to slip, and so on.

This extremely simple model is found to be capable of illustrating most of the phenomena which metals exhibit when tested in any way under mechanical stresses not exceeding their yield points. The actual form of the model is of no importance; it can be made in many ways, so long as it fulfils two (and only two) requirements, viz., (1) the units are to be elastic up to a point and then slip frictionally; (2) all the units must not start slipping at the same extension of the model. The latter condition may be conveniently attained in either of two ways, by varying the tightness of the friction grips or by using springs of different strengths.

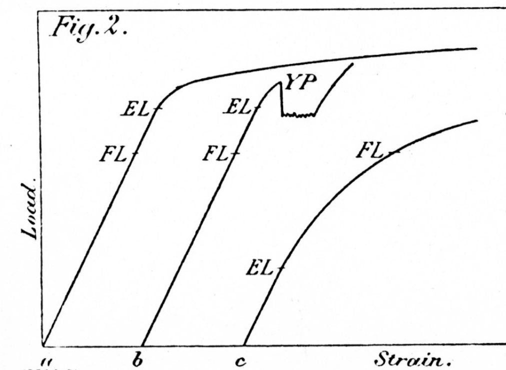
Each unit in this model represents a single crystal in the metal. The frictional slip represents the failure of the crystal along a slip plane. The crystals will fail at various extensions of the metal because they are oriented in different directions; those whose slip planes are at 45 deg. to the stress will slip first. Thus the known properties of the metal correspond with the only two requirements of the model.

Mr. Lees' model differs from the writer's mainly in that he has attempted to make a single unit, instead of a group of units, behave as the metal does, and in order to do this has had to make a modification in his model by introducing what may be described as a cam, which can hardly represent any reality in the metal. The writer's model is essentially built up of many units, the more there are the more closely it will reproduce the behaviour of the metal test pieces. The fundamental principle, however, of the two models is the same.

To make the writer's model represent different metals or different conditions of the same metal it is only necessary to vary the frictional grips in the different units and to adjust the units so that some of the springs are initially under tension and some under compression; the whole model will adjust itself so that the tensile forces balance the compression forces. By making suitable adjustments the model can be set for carrying out any of the following tests:—

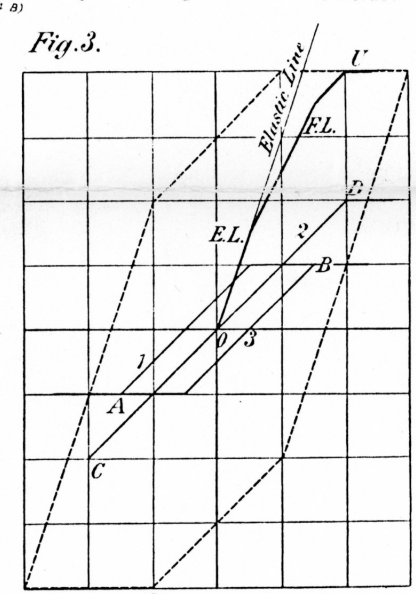
(1) *Tensile test.*—It will give all the three typical load-extension diagrams shown in Fig. 2, viz., (*a*) for tempered steel, in which the limit of proportionality is above the fatigue limit; (*b*) for soft

Fig. 2.



(7554.B)

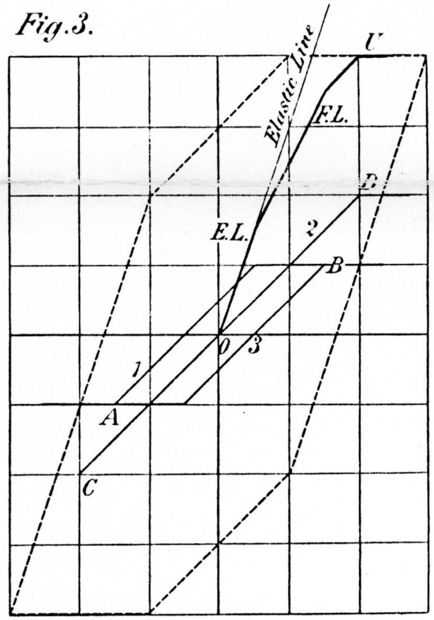
Fig. 3.



Copper.
Unit 1 Extended ½ Inch.
" 3 Compressed ½ "
" 2 Neutral

(7554 C)

Fig. 3.



Copper.
Unit 1 Extended ½ Inch.
" *3 Compressed ½* "
" *2 Neutral*

(7554 C)

iron, with a strongly-marked drop at the yield point; (*c*) for very hard steel or copper, in which the limit of proportionality is very low (or zero) and much below the fatigue limit. The load-extension curve given by a model of three units only is shown in Fig. 3. The spring in unit No. 1 is extended ½ in., in unit No. 3 compressed ½ in., and in unit No. 2 is neutral. The grips in Nos. 1 and 3 are equal and in No. 2 is twice as great. Adjusted in this way the model represents very hard steel or copper. It will give the hysteresis loops for any of these metals of the typical shapes shown by Bairstow (Phil. Trans. R.S., A Vol., 210, p. 38), with a curved rising line and straight falling line. Fig. 3 shows a hysteresis loop given by the model adjusted as stated above. By increasing the number of units these angular figures may be rounded off to any extent.

(2) *Fatigue tests.*—(*a*) When tested under alternating tensile and compressive forces the model will give a complete series of fatigue ranges. The usual way of plotting these is to plot the fatigue range against the lower stress. It is commonly stated in textbooks that the resulting curve is a parabola (Gerber's parabola). The model will not give a parabola, but gives two straight lines. Bairstow has shown that these two lines are the true curve (*loc. cit.*); (*b*) it will account for the remarkable short bursts of heat which occur at each increase of load in fatigue tests on some metals, notably in nickel, and also the fact that these bursts do not recur when the test is repeated on the same test piece; (*c*) it will explain the way in which reversals of stress make copper elastic; (*d*) it will account for the change in Young's Modulus which occurs shortly before fatigue samples finally break.

The load-extension curve for metals rises considerably after passing the yield point. To make the model show this rise, some of the units would have to be made elastic for very large extensions (of the order of 10 per cent. to 50 per cent.). It is impossible to suppose that any of the crystals are so elastic, but it is conceivable (on the amorphous theory) that the amorphous envelopes round the crystals should act in this way. An alternative explanation is that the friction increases as the crystals slip—the model could be made to illustrate this, but it would introduce a third requirement which does not correspond with any ascertained property of the crystals. The true explanation (the writer believes) is that the rise is due to the mutual interference between the crystals which must occur as soon as the metal begins to distort beyond the elastic range. This explanation does not exclude the possibility that part of the rise may be due to the amorphous envelopes and part due to changes in friction, but it shows that it is useless to try to modify the model, for the very complex interferences which must occur between neighbouring crystals could not be shown in any real way by a model.

Whether the model is a true representation of what occurs in metals can be checked in a number of ways. Several of these checks have already been applied with satisfactory results. One check has already been referred to; the model gives straight lines instead of Gerber's parabola. In the fatigue tests on nickel and some steels which exhibit heat bursts, the model shows that no heat bursts can occur below the limit of proportionality; this has been confirmed experimentally for nickel and is being checked for steel. The model shows that in Gough's tests on copper the range of elasticity conferred on the copper should be the same as the range of alternating stress applied (up to the limit of proportionality). This test has been made and confirms the prophesied result. Check tests on other points are now in hand at the National Physical Laboratory. So far as the writer is aware, the behaviour of the model does not conflict with any known property of metals. A full account of the model will be published when the tests now in hand have been completed.