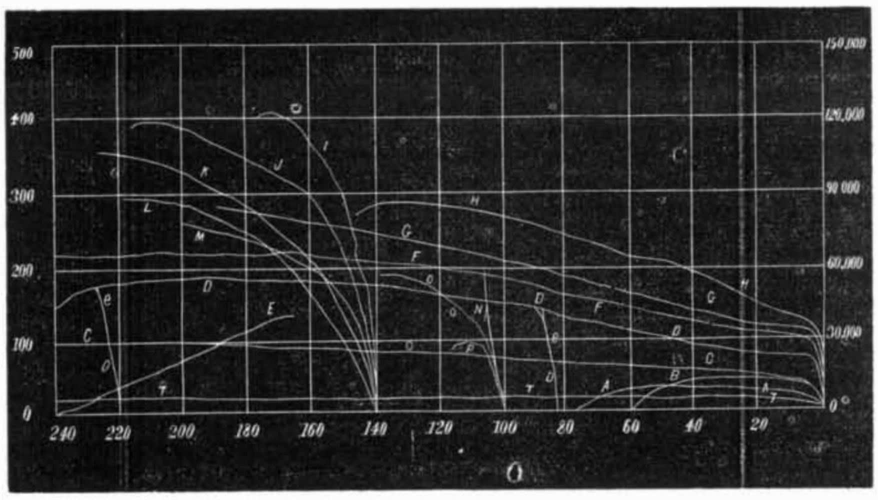
STRAIN DIAGRAMS AND THEIR REVELATIONS.

BY PROFESSOR R. H. THURSTON.

In the preceding article, a brief account was given of the method of formation of strain diagrams, whether made by plotting the results of experiments (made as described in the illustrated article published in the SCIENTIFIC AMERICAN of January 17, 1874) or by an autographic testing machine; and an explanation was given of the method of obtaining valuable and interesting information by the interpretation of the initial portion of the diagram.

In the figure here given are rough copies of several complete strain diagrams, produced by the autographic torsion machine at the Stevens Institute of Technology, by which this novel internal examination of materials, and its revelations, can be more completely exhibited.



The curves here shown do not exhibit the effect of peculiarities in the material as perfectly as the originals, because it is necessary to reduce the horizontal scale very much in order to bring the figure into proper shape and size to enter the columns of this paper. The original strain diagrams of iron occupy a space nearly a yard long and but two and a half inches high. Those of steel are five or six inches high. The column of figures at the right of the engraving represents the maximum stress per square inch of section exerted upon the fibers of the metal by tension, when the product of the weight on the end of the lever by its leverage is equal to the figure at the opposite end of the plate.

Referring to the figure, the curve, A, is that of zinc. Its form at the commencement, concave toward the base, shows its inelastic nature. Its gradual rise shows that it may take a set under the action of the smallest forces. Its maximum hight is small in comparison with its companion curves, and this shows its weakness; it actually has a strength, in tension, of but about 10,000 lbs. per square inch, and this was an unusually good specimen. Breaking off at about 65°, we learn that its ductility is slight, the metal only stretching about four per cent. Tin, T, is still weaker but vastly more ductile, and its strain diagram runs quite off the sheet, the metal twisting completely around before breaking; but its maximum resistance only reaches about 5,500 lbs. per square inch. B is the curve of cast copper, and C, that of forged copper. Could we follow the latter to the end, we would find that the specimen had yielded through more than 500°, its fibers stretching to three times their original length. It exhibited a resistance equal to over 28,000 lbs. per square inch. Its limit of elasticity, that is the point at which it begins to take a set nearly proportional to its distortion, is at a very low strain, less than 10,000 lbs., and it yields very considerably before it offers its maximum resistance. Its ductility is its most remarkable quality. Cast copper contrasts strikingly with the forged metal. Its limit of elasticity occurred at about 5,000 lbs. per square inch, its ultimate strength was between 12,000 and 13,000 lbs. per square inch, and its elongation was but two and a half per cent. This piece was from carefully selected ingot copper, cast in dry sand at the Stevens Institute of Technology. It, like the majority of the specimens here described, is therefore an unusually good example of cast copper; and were it of impure scrap, or had it been cast in green sand, its inferiority to forged copper would have been still more marked. Green sand seriously injures the metal by the production of porous castings, rendered spongy by vapors from the damp mold.

Good wrought iron gives the line, D. The beginning of the diagram, a line nearly straight but slightly curved in a direction the reverse of the preceding, and inclined toward the left, shows plainly that this is a somewhat elastic material, having a little internal strain. The short stretch of nearly horizontal lines, which appears far more distinctly in the original diagram, indicated that it is a fibrous iron, well worked and rather hard. It takes a set at very nearly 20,000 lbs. per square inch, and its maximum resistance is nearly 60,000 lbs. It finally breaks at some point beyond 240°; its maximum elongation is about one half, on some lines of fiber.

On this strain diagram will be noticed two of the lines exhibiting elasticity. They are apparently perfectly parallel, a fact which proves, what had already been suspected and almost proved by more than one distinguished philosopher, that elasticity remains unimpaired until fracture actually commences. Comparing the inclination of these lines, *e e*, with that of the initial part of the diagram, we find all very nearly of the same inclination; and the deduction, already made from the slight curvature of the beginning of the diagram, that this iron is very slightly weakened by internal strain, is thus confirmed. The line, E E, shows the form of the terminal portion of the diagram when the metal is very tough and ductile, like Swedish iron, for example. With ordinary irons and with steel, the curve ends abruptly, as shown in all those here given. The diagram, F F, is that of the excellent iron, referred to in the previous article as having given a curve of such beautiful regularity. The line exhibits perfection in quality by its great symmetry and smoothness. Were it shown *in extenso*, it would be seen that the specimen only broke after a complete revolution, and that the metal is as remarkable for its strength and ductility as for its homogeneousness and purity. This is the specimen illustrated and described as No. 22 in the article of January 17, 1874.

The effect of the presence of carbon upon the properties of iron is shown by the succeeding diagrams. A low steel, containing 0 4 per cent carbon, and produced by the Bessemer process, tells its story at G. The line H, is that of a Siemens-Martin steel, containing one half per cent or a trifle more of carbon, while I and J are tool steels; K and L are medium and spring steels, and M is the strain diagram of double shear steel. It is seen, at a glance, that the introduction of carbon lessens the ductility of the metal, while increasing its strength and raising the elastic limit. The least ductile are the tool steels containing one per cent and upward of carbon. The most ductile is pure iron, containing no measurable quantity of that element. Intermediate degrees of ductility are produced by intermediate proportions of carbon. Their strengths vary in the opposite direction, increasing with the dose of carbon, in a pretty regular proportion, which is expressed quite accurately, for unhardened steel, by a formula, constructed by the writer: $T = 60,000 + 70,000\ C$, in which T represents the tenacity in pounds per square inch, and C, the percentage of carbon present in the given steel. In the low steels, the lack of homogeneousness, due to porosity in the ingot, is seen to be much more noticeable than in the tool steels, which are rendered more quiet in the mold by their higher proportion of carbon and of manganese.

In these high steels, the limit of elasticity, for the unhardened, is seen to rise to 60,000 lbs. and the ultimate strength to over 120,000 lbs. per square inch. The elongation is reduced by the maximum dose of carbon to about one and a half per cent.

N and P are the strain diagrams of white and of gray cast iron. The one is stiff, hard, strong and brittle, its line rising steadily upward without a sign of curvature or ductility until it suddenly snaps, after sustaining a very heavy stress. The other offers barely a half as much resistance; the curve bends sharply and runs a little way to the left, and breaks after the piece has twisted less than 20°, indicating a strength of but a half of one per cent. It has, however, five times the ductility of the white iron.

Malleableizing the white iron, a material is obtained of which the line, O, represents the characteristics. It is very homogeneous, has lost no strength, and has gained immensely in ductility. For many purposes it is better than average wrought iron; and the readiness with which irregular forms may be made of it, if of small size, makes malleableized cast iron a very useful material. "Steel" castings are usually made of an exceptionally good quality of this metal.

Glancing over the collection of strain diagrams, it is easy to select the proper kind of iron for any specified purpose. If mere strength is required, it is evident that the tool steels are the best materials. If ductility is desired, something resembling Swedish iron is the proper metal. Comparing the qualities of several metals experimented upon with the price lists, we may readily determine which is cheapest for the specified work. When shocks are to be resisted, or blows sustained, strength alone is not sufficient. Tool steel is too brittle a material to be used in such situations, and even moderately hard steels were long ago found to be less valuable than moderately good iron for such purposes. That metal which is at once strong and ductile is the proper one to choose. The power of a substance to sustain live loads—its resilience—is measured by the product of its mean resistance into the distance through which it stretches before breaking. A close approximation may be obtained by multiplying two thirds the ultimate strength by the distance through which elongation takes place. The metal giving the highest product is the safest against rupture by blows. Of two metals giving equal products, choose that which is strongest.

An area of the strain diagram measures precisely the value of a material to meet shocks. It is exactly proportional to the product just referred to, and its construction affords the only means, yet discovered, of determining resilience with precision. Examining the diagrams, it is seen that, except the very purest and most expensive wrought iron, the low steels excel all other materials in this respect, while they are stronger than any iron; and we perceive a very excellent reason for the wonderfully rapid introduction of Bessemer and Siemens steels, in rail and machinery making, which has recently taken place. A steel containing less than one half per cent carbon is not affected injuriously by changes of temperature, cannot be hardened, has at once great strength and considerable ductility, and is the best known metal, all things considered, to be placed wherever a structure is liable to severe blows and heavy strains, and therefore must be both light and strong.

Much more could be learned by the study of our strain diagrams, but space will not permit further examination of this method of molecular inspection, which physicians might probably term a stethoscopic examination of materials used in construction. Should the opportunity offer, we may, at some future time, be able to discuss some of the more novel facts which have been learned by the application of this new method and apparatus to research in a field in which much has been done, but in which there still remains much to be discovered.

STEVENS INSTITUTE OF TECHNOLOGY.

A Six Acre Rolling Mill.

The Phœnix Iron Company, whose great works are at Phœnixville, Pa., about an hour's railway ride up the Schuylkill from Philadelphia, have nearly completed a new rolling mill building, which is noteworthy in several respects. The *Ledger* says it is believed to be the largest single mill building, under one roof, in this country. The ground plan covers about six and a quarter acres of ground. Its longest dimension is nine hundred and thirty-eight feet. and its breadth is two hundred and ninety feet. The principal material of the building is wrought iron, the roof being slate. The building rests upon about two hundred and fifty wrought iron flange columns of three eighths thickness of iron, of the well known Phœnixville pattern. These rise about thirty feet to the eaves of the roof, and are but eight and a half inches in diameter through the cylinder, and about twelve inches in diameter from the tip of one flange to the tip of the flange on the opposite side of the column. At a short distance they look very slender, considering the great expanse and weight of the superstructure they have to support, but they have been proved to be capable of sustaining many times the greatest weight or force they are ever likely to have to resist. The roof rises to the hight of sixty feet at the ridge, the framework being exclusively of wrought iron, firmly braced and tied with rods and links. The furnaces, engines, and machinery will cost nearly a million of dollars. The cost of the building will be about $280,000.

Elongation of Conductors by Electricity.

Various physicists have from time to time studied the modifications in the molecular state of conducting wires, due to the passage of the electric current. Wertheim arrived at the conclusion that the transmission of the current modified the elasticity of the conductor, but Edlund, on the contrary, by a long series of careful experiments, has determined such not to be the case. This latter investigator has found, however, that the elongation of the wire under the influence of the current is sensibly greater than the dilatation due to the elevation of temperature resulting from the passage of the electricity. Two calculations were made of the temperature of the wire, one deduced from the relation previously established between the galvanic resistance of the conductor and its temperature, the other from the elongation of the wire directly measured and of its coefficient of dilatation, equally known. The second mode of determining the temperature constantly gave higher figures than the first, and M. Edlund therefore concluded that the current produced a special elongation in the conducting wire which is added to the expansion resulting from the accession of heat.

Quite recently M. Streintz has taken up this subject, and, by further investigation, has sought to measure accurately the galvanic elongation for different metals.

The observations were made on wires 0 019 inch in diameter and 21 inches in length, the ends of which just touched two levers which carried mirrors placed in the prolongation of their axes of rotation. The divisions of a graduated scale were reflected in the mirrors, and thus the displacement of the extremities of the wires could be accurately read. All the wires except those of hard tempered steel showed a marked excess of expansion under the action of the current, which varied, according to the different metals, from 11 to 27 per cent of the dilatation of the wire under the action of heat alone when brought from the normal temperature, 68° Fah., to that fixed as a limit, 131·4°.

M. Streintz sums up his results as follows: 1. The galvanic current causes no other modification of the elasticity of a conducting wire than such as results from the elevation of the temperature produced.

2. Under the action of the current, the conductor expands more than when it is carried to the same temperature without the current; tempered steel alone does not present this excess of dilatation.

3. Galvanic dilatation does not manifest itself immediately on the closing of the current, but gradually, as does calorific expansion.

4. Galvanic dilatation is not the consequence of an electro-dynamic repulsion, but probably results from a calorific polarization or an orientation of the calorific vibrations.

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THE superior effect of kindness over brutality, in the management of balky or restive animals, is forcibly illustrated in the following incident, related of one Sam Jones, who lived up in Orange county, N. Y. Now Sam was an enormous eater, and it happened that he was one day hauling a load to the nearest village, when his team was stuck in a sand hill. Well, did Sam fret and scold his oxen or unload his team? Not he. He very coolly took down his dinner from the load and sat down and ate it, when his oxen started off with the rest of the load without further trouble.

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