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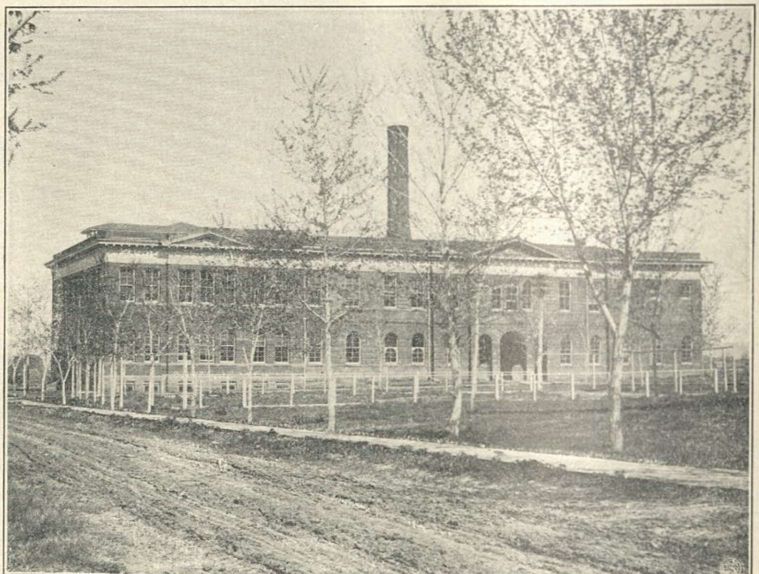

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JOURNAL OF ENGINEERING

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APPLICATIONS OF THE FUNICULAR POLYGON TO CONTINUOUS LOADS.

BY ARNOLD EMCH, PH. D., PROFESSOR OF GRAPHICS AND MATHEMATICS.

There is hardly a geometrical principle which is of greater and more general practical value than that of the funicular and force-polygons. It was first studied by VARIGNON in his *Nouvelle Mecanique* (Paris, 1725). PONCELET used it in his lectures at the Artillery School of Metz, for the determination of centers of gravity[1]. CULMANN, however, was the first to recognize the general value of the funicular polygon for all static constructions, and introduced it as a powerful means for the solution of various problems of engineering in his now classic treatise on *Graphische Statik*[2]. It is for this reason that Culmann must be considered as the founder of graphic statics.

Important generalizations in this science were made by JAMES CLERK MAXWELL[3], by CREMONA[4] and, more recently, by the American, H. T. EDDY[5].

In this article I shall make a few simple applications of the funicular polygon to continuously distributed systems of forces, and pay particular attention to their analytic representation.

[1] *Cours de mecanique industrielle,* Metz, 1829.

[2] Published in Zurich in 1866.

[3] *On reciprocal figures and diagrams of forces,* Phil. Mag. (4) 27 (1864), p. 250. Also in his collected papers, I., p. 514, p. 598; II., p. 161, p. 492.

[4] *Le Figure reciproche nella statica grafica,* Milan, 1872. Also in the English translation: *Graphical Statics.*

[5] *A new general method in graphic statics,* Van Nostrand's Engineering Magazine, 1878, p. 12. Also in numerous other publications.

Continuously Loaded Horizontal Beam.

Let AB be the upper edge of a cross-section of a horizontal beam coincident with the x-axis of a Cartesian system, and assume the perpendicular to AB at A as the y-axis (Fig. 1). The directions of the forces acting on the beam shall be vertical and in the xy-plane and consequently parallel to the y-axis. The law of the distribution of these forces continuously distributed over the beam shall be given by the function

$$y = f(x).$$

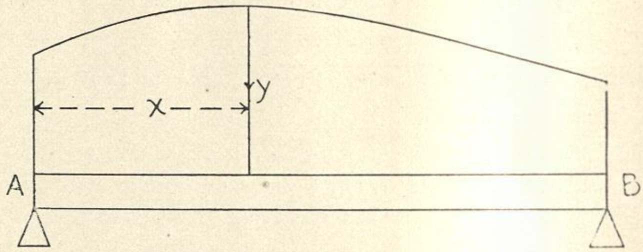

Fig. 1.

The meaning of this function shall be that at a distance x to the right of A, the acting force per unit of length is y force-units. The designation of the particular units is arbitrary, so that the following developments will hold for English as well as for Metric units. From the assumptions it follows that $f(x)$ within the limits considered is a continuous function, and that for $x = o$ and $x = l$, where l is the length of the beam, the values of the function are $f(o) = a$, $f(l) = b$, definite constants. The whole load is clearly

$$Q = \int_o^l f(x)\,dx,$$

while the load out to a distance x is

$$\int_o^x f(x)\,dx.$$

To construct the force-polygon of the given forces we assume another rectangular co-ordinate-system (η, ξ) whose axes are parallel to the x- and y-axes. The force-polygon consists of a vertical line which we assume coincident with the η-axis. The ordinate η shall represent the negative sum of forces acting over a distance x of the beam, so that

$$\eta = -\int_o^x f(x)\,dx.$$

For $x = o$, $\eta = o$; for $x = l$, $\eta = -\int_o^l f(x)\,dx.$

To construct a funicular polygon of the given system of forces assume the pole O in the $\xi\eta$-plane with the arbitrary co-ordinates m and n (Fig. 2). Then, the slope of the initial line of the funicular polygon will be $\frac{n}{m}$ and of the final line $\frac{n + \int_o^l f(x)\,dx}{m}$.

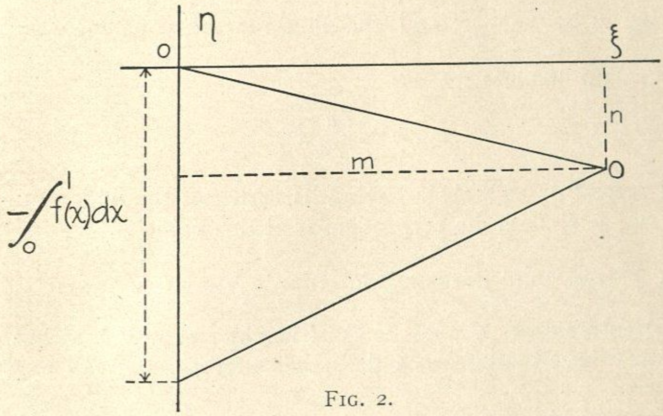

FIG. 2.

In general the funicular polygon will cut the direction of the force acting on the beam at a distance x, at an angle whose slope is

$$\frac{dy}{dx} = \frac{n + \int_o^x f(x)\,dx}{m},$$

since this slope is identical with the slope of the tangent to the funicular polygon at that point. Solving this differential equation we get the equation of the funicular polygon:

$$y = \frac{n}{m}\,x + \frac{1}{m}\int_c^x \left[\int_o^x f(x)\,dx\right] dx.$$

The lower limit c of the first integration brings in the constant of integration.

EXAMPLES.

1. Uniformly Distributed Load.

In this case $y = a$, a constant. The whole load is $Q = \int_o^l a\,dx = al$. For the sake of simplicity we take $n = -\frac{al}{2}$ and m arbitrary, so that the equation of the funicular polygon becomes

$$y = -\frac{al}{2m}x + \frac{1}{m}\int_c^x\left[\int_o^x adx\right]dx\ ,$$

$$\text{or}\quad y = -\frac{al}{2m}x + \frac{ax^2}{2m} + \text{const.}$$

Choosing the origin of co-ordinates at the midpoint of AB; *i. e.*, replacing x by $x+\frac{l}{2}$; and choosing for the constant $c = -\frac{al^2}{8m}$ this equation becomes

$$y = \frac{a}{2m}x^2,$$

which represents a parabola having its vertex at the midpoint of the beam and as an axis the perpendicular at this point.

2. Hydraulic Pressure Against a Vertical Wall.

Given a smooth vertical wall of height l against which a mass of water whose level reaches the upper edge of the wall exerts its pressure.

Consider the pressure in a vertical plane perpendicular to the wall. This evidently comes under the case of a continuously loaded beam. As the direction of the forces is now horizontal we shall, in the general development, interchange x and y. The law of the distribution of forces is in this case

$$x = -k\,.y,$$

where k is a constant easily to be determined. The equation of the funicular polygon becomes

$$x = \frac{n}{m}y - \int_c^y\left[\int_o^y kydy\right]dy\ ,$$

$$\text{or}\quad x = \frac{n}{m}y - \frac{k}{6}y^3 + \text{const.},$$

which represents a curve of the third order. To find the center of pressure of the mass between the level $y = o$ and the depth y, we have to remember that the tangents at the extremities of a funicular polygon intersect each other in a point of the resultant. The equations of the tangents at the points (o, o) and (x_1, y_1) of the funicular curve are

$$y = \frac{m}{n} x,$$

$$y - y_1 = \frac{dy}{dx} (x - x_1);$$

or

$$y = \frac{m}{n} x,$$

$$y = y_1 + \frac{1}{\frac{n}{m} - \frac{k}{2} y_1^2} (x - x_1).$$

Solving simultaneously we find for the ordinate of the point of intersection of the two tangents $y = {}^2/_3\, y_1$; *i. e.*, the center of pressure lies at two-thirds of the whole depth below the level: a well-known result.

Other Problems of a Similar Character.

In the foregoing problems systems of parallel forces were considered. The method employed may easily be extended to general systems of continuous forces. I have studied problems of this kind in the *Industrialist* of 1899, in an article on "Some Applications of Modern Geometry to Mechanics." There, it was shown that the funicular polygon of a system of forces uniformly distributed over the circumference of a circle is an involute of that circle, a result which was used for the construction of a mechanism, transforming a uniform rotation into a uniformly oscillating translation.

Another problem of this class may be stated in the form: Given a perfectly flexible cylindrical surface bounded by the two elements *AB* and *CD* forming a rectangle in a horizontal plane and two vertical planes through *AC* and *BD*. If the vessel formed by the cylindrical surface and the vertical planes is filled with water, what will be the shape of the surface after equilibrium has been attained?

A solution of this interesting problem will be published in the near future.

MULTIPLE-VOLTAGE SPEED CONTROL FOR MOTOR-DRIVEN MACHINE TOOLS.

By Lucius I. Wightman, B. S. (E. E.), 1899.

The comparative merits of electrical and mechanical methods of machine-shop drive have been so widely discussed in the technical press and in papers before the engineering societies that any further elaboration of argument on this point seems unnecessary. It is the belief of the writer, however, that the weight of advantage is generally acknowledged to be on the side of the electrical drive; and this paper is a frank avowal of a faith in the judgment of abler, more experienced men.

Without going into troublesome detail, and leaving out of the question, for the moment, all methods of speed control, the following items may be justifiably set forth as recognized advantages of electrical methods applied to machine-shop drive:

1. It largely dispenses with the use of shafting, hangers and heavy pulleys, permitting a simpler and cheaper construction of the shop building.

2. It avoids the use of the multitudinous overhead belts, giving better lighting, freedom from flying dust, dirt and oil, and providing clear head-room for the operation of traveling cranes, with all their economic value.

3. Machine tools can be arranged to suit the shop methods and the special character of the work, admitting of most approved shop organization and the utilization of floor space to the best possible advantage.

4. The system gives the most ready and economical adaptation to all future changes, increases and extensions in shop lay-out.

5. Portable tools can be most readily used, with all their attendant advantages for the heavier class of work.

6. Each tool is absolutely independent of every other and when idle consumes no power.

7. The system assures freedom from liability to a general shut-down due to the breaking of a line shaft or a main driving belt.

8. It furthermore reduces the liability to accidents to employees—in the great majority of cases chargeable in some way to belts and shafting.

9. There is no power consumed in transmission gears, long lines of shafts and counters, in pulleys and belts.

10. The system permits, therefore, a smaller power plant for driving the shop, and reduces the power charge not only in the matter of fuel and water consumption, but also in labor and maintenance over the whole power scheme.

The points of advantage enumerated above may broadly be said to be characteristic of any system of electrical shop drive. There may be individual systems in which some one or more of these advantages loom into larger proportion than others; and the logical trend of thought leads to an investigation of the separate system. Again, the writer must state his position, at the outset, firmly on the side of a certain scheme of shop drive—that of the individual motor unit. But that he may not seem to be altogether unjustified in his attitude, the following remarks of a recognized authority are quoted.

In a paper read before the American Society of Mechanical Engineers, Prof. C. H. Benjamin says: "No doubt it is true to-day that the question of time is more important than that of power, and that in the endeavor to get the most product per machine and per man, the minor subject of coal and water consumption has been overlooked."

This is an age of intensified methods; as Prof. Benjamin says, the tendency is to work men, machines and materials to the limit. And in a large shop, with diversified processes and varied classes of work, it is manifestly impossible to secure the maximum from a tool which is dependent in any degree upon a neighboring tool which may be engaged on a totally different process. Only when a machine is absolutely independent of any other can it be worked to its fullest capacity and maintain a maximum output. Again, speaking broadly, it may be said that, in addition to the ten advantages previously listed in favor of electric drive, the individual motor system has this merit also: it permits each tool to be worked at maximum capacity all the time.

To quote further from Prof. Benjamin's valuable paper: "When it is necessary to use independent and direct-connected motors on cranes and on machine tools, prompt and economical speed control is an absolute necessity. * * * Without any prejudice, it is the earnest belief of the writer that the greatest advantages in electrical transmission are to come from the use of independent motors to the largest extent possible, and that the day will come when nearly every machine in the shop will have its own motor. * * * The principal difficulty in designing direct-current motors for machine tools has been that of getting slow speed without great weight and of securing proper speed variation without seriously impairing the efficiency."

Though these statements were made some years ago, they are as trenchant to-day as when uttered, and contain concise statements of the vital problems confronting the shop engineer in relation to electrical drive. The advantages of the individual motor for the machine tool are no longer questioned by engineers. But the obstacles which for years stood in the way of its general adoption are ably summed up in Prof. Benjamin's paper: "The difficulty of securing the minimum size of motor for a maximum capacity without high speed—a problem involving first cost or initial investment; and the difficulty of securing prompt, ready and economical speed variation—questions affecting the shop output and power charges."

The multiple-voltage system of motor speed variation as developed by a prominent electrical manufacturer has brought to the engineer and manager a solution for many of the difficulties encountered in modern intensified production methods. It has passed through the experimental stage and has taken its permanent place among the useful industrial applications of electric power. Its adoption and successful operation in scores of manufacturing establishments in America and abroad attest its recognition as an economic factor in production.

Briefly stated, it is a method of varying the speed of motors—and of the tools to which they are connected—by supplying the motor armature with current at different voltages, while the motor field with a variable resistance in series is continuously excited from a specific constant voltage. The advantages of the system are five-fold:

1. When the motor is set to run at any speed, it will maintain that speed practically constant, regardless of changes of load upon it.

2. The variation in speed is secured without the dead loss of power occasioned by introducing resistance in the armature circuit.

3. The efficiency of the motor over its entire speed range is higher than that secured by any other method of speed control.

4. The motor is at all times operating at or very near its maximum output.

5. A motor of special design is not required; a standard machine is employed, equipped with the necessary controller.

In all systems of variable speed control where the variation in speed is due to electrical change and where a constant available horse-power is required over the entire range of speed, the motor will always have to be larger than would be required where a constant speed motor is used in connection with a mechanical speed-changing device. This is true whether the system is one of speed variation by multiple voltage, field resistance, or armature resistance. It is essential because in such case the motor *must* be large enough to give its maximum duty at either its highest or its lowest speed. Under normal conditions of full voltage and full field strength such a motor will have a capacity in excess of that required to do the work at either extremity of the speed range.

The most economical arrangement, and the one which would permit the use of the smallest motor, is that one in which the motor would be worked to the limit of its capacity at both maximum and minimum speeds. A combination of the two methods of control—shunt field resistance and variable voltage—embody to a great extent the advantages of both systems and permit the use of a motor smaller than either scheme alone would require. Moreover, that system which utilizes resistance in the shunt field to weaken the field to a point where the capacity of the motor is just equal to its capacity on the lowest voltage of a variable voltage system, will demand the minimum size of motor while permitting that motor to work over a maximum speed range. Such a combination results in a system of motor drive which complies with the two fundamental requirements defined in Prof. Benjamin's paper: motor of minimum size, and proper speed variation. And such is the system of multiple-voltage speed control for motors as developed by a prominent electrical manufacturer.

Before entering upon a description of this particular method of shop drive, a general consideration of the requirements of modern machine-shop practice may be of assistance in understanding the machine-tool situation. A marked feature of modern methods is the almost universal tendency to work men, machines and materials to the limit of endurance. Maximum output at minimum cost is the keynote of up-to-date production; and the manufacturer who does not recognize this and make his plant conform to the demands of this tendency, is not unlikely to find himself rudely shouldered aside by a more progressive and alert competitor. Among the strongest factors in this strenuous method of production as applied to the machine shop are the Taylor-White and kindred processes of hardening tool steel. They have placed in the hands of the shop superintendent a tool which enables him to increase his output per machine to a degree which is only beginning to be realized. These secure a speed range of 60 to 1 by purely electrical means, a motor is required of a size out of all reason. But the introduction of one set of gears, properly proportioned, will simplify matters hugely. For every lathe is equipped with at least one set of back gears, which will be available with motor drive, as well as under belt drive; and if the motor itself has a speed ratio of 7.2 to 1, and the back-gear ratio in the lathe is 8.2 to 1, the tool will have a total speed range represented by the ratio of 59 to 1, the product of the two individual ratios. Herein appears the importance of properly proportioned back gears. While there seems to be no general agreement among American builders, experience indicates an average back-gear ratio in common practice between 12 to 1 and 15 to 1. The meaning of this will be best appreciated by another specific instance, in which a four-cone pulley gives speeds increasing by 50% intervals, and the back-gear ratio is 12 to 1. Assume that the counter gives to the spindle direct speeds of 33, 22.5, 15 and 10 r. p. m. through the four cones. The back gear is such that the highest speed, with the gear in, is 1/12 of the highest with gear out; giving, in this case, a maximum spindle speed, with back gear in, of 2.75 r. p. m. The total speed range, then, with cones and back gear, will be as follows: 0.8, 1.2, 1.8, 2.7, 9.6, 14.4, 21.6, 32.4 r. p. m. Note the gap in the speed curve where the back gear goes out; and consider what it means in economic practice. The importance of properly proportioned back gears becomes apparent.

Before leaving the machine tools of this class, it will be well to emphasize the fact that, in machines properly coming under this classification, nearly all the power is consumed in effective work and but a very small portion absorbed in the tool itself. This last work is not a constant quantity, but increases somewhat with the spindle speed and with the weight of the piece machined. But for purposes of general discussion, it is safe to consider the proportions of power consumed in useful and wasted work as bearing constant ratios, for any given cutting speed on any given tool.

Turning now to machines of the second division into which machine tools are classified—those required in machining plane surfaces—their characteristic is found to be a practically constant torque, with a power varying with the speed. Be it further stated that, in tools of this class, a very large percentage of the total power is consumed in the mechanism itself, and that this power increases with the speed. The planer may be selected as a typical machine of this class; and analyzing its operation, there is found to be a forward motion at cutting speed, a sudden reversal, a return at still

higher speed, and a second sudden reversal. A large proportion of the total power is consumed in these reversals and, the number of the reversals being proportional to the speed, it is evident that this power increases with the speed. The same features mark the operation of shapers, slotters and similar reciprocating machine tools. In tools of this class the speed range required is small; for it is evident that the cutting speed does not vary with the progress of the operation. The only variation of speed required is that necessary to secure a maximum cutting speed at the beginning of an operation; this speed depending upon the quality of the tool steel used and the material machined. When the speed has once been properly set for a given job, the cutting speed—and hence the motor speed—will remain constant through that operation. The torque will have a practically constant value and the power will vary with the speed.

The multiple-voltage system has already been briefly described as a combination of straight multiple-voltage and field-resistance control. Intermediate between the speeds secured by direct voltage change, are speeds secured by the insertion of resistance in the shunt field of the motor, this field remaining constantly excited from the maximum voltage. A multiple-voltage equipment includes: either a multiple-voltage generator, or a balancer connected across the mains of a constant-voltage generator; a motor of suitable size connected to each tool where speed variation is required; a controller for each motor; and a system of distribution for the several voltages. The system is offered in two forms, known as the Three-Wire and the Four-Wire Systems. These two afford the same total speed range; and the only essential difference between them lies in the number of distinct variations of speed possible within this range. The speed curve obtained under either system is almost a true geometric curve; *i. e.*, the speed increases by a constant *percentage* of increment; not by a constant *number* of revolutions added at each notch.

The standard Three-Wire System has three basic pressures—90, 160 and 250 volts. The production of current at these three voltages is the first step of the problem. It is susceptible to two solutions: The first is the installation of a distinct three-voltage generator; the second is in the installation of a "balancer" across the mains of a constant-voltage generator, the function of which is to split the primary voltage of 250 into the two subsidiary pressures of 160 and 90. The first solution is not practical in the vast majority of cases. For in every shop-installation of any magnitude, only a part of the total electrical power is applied on variable speed higher speed, and a second sudden reversal. A large proportion of the total power is consumed in these reversals and, the number of the reversals being proportional to the speed, it is evident that this power increases with the speed. The same features mark the operation of shapers, slotters and similar reciprocating machine tools. In tools of this class the speed range required is small; for it is evident that the cutting speed does not vary with the progress of the operation. The only variation of speed required is that necessary to secure a maximum cutting speed at the beginning of an operation; this speed depending upon the quality of the tool steel used and the material machined. When the speed has once been properly set for a given job, the cutting speed—and hence the motor speed—will remain constant through that operation. The torque will have a practically constant value and the power will vary with the speed.

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The motors for machine tool service under this system are standard shunt wound machines, preferably rated at 600 r. p. m., 250 volts; for in the majority of cases this speed lends itself most readily to gear connection, though there may be cases where 300 or even 900 r. p. m., 250-volt motors will serve better. The controller is of single-drum type and gives twelve forward speeds and nine on the reverse. The order on the forward direction is: one notch 90 volts direct, with two notches full resistance at 90 volts; one notch 160 volts direct, with two steps of field at 160 volts; one step 250 volts direct, with five notches field resistance at 250 volts. In some cases, as where the gearing is somewhat delicate, or the piece machined very heavy, the sudden throwing on of a higher voltage would cause sudden, and possibly dangerous, strains. For such cases, an automatic solenoid switch is connected in, which, at each increase of voltage, throws resistance for a few seconds *only*, into the armature circuit and so eases the strains. Armature resistance *as a steady control*, has no place in this system. The twelve forward speeds correspond to a speed range from 200 to 1,200 on the motor, or a ratio of 6 to 1. Experience has shown that 1,200 r. p. m. is about the maximum limit of speed for geared motors, such as this system contemplates. But this limit is set by mechanical, not by electrical, considerations—by the gearing, not the motor. There may possibly be cases where this maximum could safely be exceeded.

In the Four-Wire System, there are three primary voltages—60, 80 and 110—from which by combination are secured 140, 190 and 250 volts. These pressures may be secured by a multiple-voltage generator or, preferably, from a three-machine balancer connected across the 250-volt mains of a constant-voltage generator. The operation of this balancer will be practically the same as that of the two-machine balancer described, and further discussion of the production of six voltages is unnecessary. In this, as in the three-wire system, the interesting point is that a very small balancer will provide for a very large variable speed load; and the greater the number of variable speed motors, the better the operation of the balancer. The lighting and constant speed motor load will again be carried on the 250-volt generator. The variable speed motors used under this system are standard shunt-wound 250-volt machines. The four-wire controllers are of double-drum type, giving twenty-six forward speeds and six on the reverse, covering a total range of speed of 200 to 1,200, with a ratio of 6 to 1.

The choice between the three-wire and four-wire systems will in any case be determined by characteristic conditions. It is seen that the speed range in either case is the same, and about the only advantage of the four-wire system over the three-wire appears to be in the refinement of speed variation within this range. The three-wire system gives a range from 200 to 1,200 r. p. m. in twelve divisions of approximately 20% increase at each notch. The four-wire system gives the same range in twenty-six increments of about 8% each.

As a basis of comparison of the merits of the two systems, continue the discussion of an example already cited. The problem was that of machining a 15-inch shaft at a maximum cutting speed of 60 feet per minute. It was found that the nearest practical speed with cone pulleys was 47 feet per minute, at a spindle speed of 12 r. p. m. Assume that this same tool is connected in on a three-wire multiple-voltage system with motor so geared that one notch of the controller gives 12 r. p. m. The speed increments being 20%, the next notch of the controller will give 14.4 r. p. m. corresponding to a cutting speed of 56.5 feet on the 15-inch piece—92% of the maximum sought.

Assume now this tool connected on a four-wire system, so geared that one controller notch gives 12 r. p. m. of the spindle. Speed increments are now 8%; and three additional controller notches will give a spindle speed of 15.1 r. p. m., giving a cutting speed of 59.3 feet on the 15-inch piece—98.6% of the required maximum.

Tabulating the comparative results secured in the three cases, the following is seen:

	Cone Pulley	Three-Wire	Four-Wire
Diameter of piece	15″	15″	15″
Spindle speed, r. p. m.	12	14.4	15.1
Cutting speed secured (ft. per minute)	47	56.5	59.3
Maximum cutting speed sought	60	60.0	60.0
Per cent required maximum secured	78.3	92.0	98.6
Per cent time lost compared to maximum	21.6	5.6	0.11

From which it appears that in this particular case the four-wire system comes about as near as possible to the ideal solution; though the three-wire system seems to come near enough for all practical purposes. In either case, the superior advantage of the multiple-voltage systems over the cone drive is strikingly apparent.

Considerations of space forbid a discussion here of the interesting questions involved in the comparative costs of the two systems of multiple-voltage three-wire and four-wire. But enough has been said to establish the superiority of this method of electrical drive as compared to the old scheme of belts and cone pulleys—and such has been the object of the present paper. The fundamental requirements of machine-tool drive were never better or more explicitly stated than in Prof. Benjamin's paper, already quoted. And it is believed that this discussion has shown that the multiple-voltage system of machine-tool drive approaches about as nearly as any system could to the ideal embodiment of the requirements there laid down.

THE DIFFERENTIAL TELEPHONE.

By Charles A. Lory, M. S., Acting Professor of Physics, and
Claude C. Coffin, Assistant in Physics.

The "differential telephone," as designed by William Duane and Charles A. Lory and published in the Physical Review, April, 1904, was tested by them as a means of comparing self-inductances. The accuracy obtained was much greater than that claimed for a previous design of telephone working on the differential principle. Since April, 1904, an extended test has been made of the merits of the differential telephone in measuring resistance and capacity, as well as self-inductance. The data obtained would indicate that the instrument will undoubtedly meet with approval in making speedy and delicate measurements.

A differential telephone receiver is one on the bobbin (or bobbins) of which two coils are wound differentially, *i. e.*, side by side and in opposite directions. By suitable means these coils are adjusted so as to have equal self-inductances, and equal resistances, so that the magnetizing effect of a current flowing through one coil will exactly annul that of an equal current flowing through the other coil. By suitable connections the two circuits about the bobbins extend, external to the receiver, and constitute the two branches of the telephone. These two branches having (when adjusted) equal self-inductance and resistance, no sound will be heard in the receiver when an A. C. electromotive force is applied at the terminals of the branches in parallel. The two self-inductances, resistances, or capacities to be compared are introduced into the two branches and their magnitudes varied until silence is produced in the receiver; it follows that they must be equal, and, by having one a variable standard, the value of the other can be found.

The general construction of the receiver is similar to that of the Bell telephone receiver. The iron core of the bobbin is four inches long and one-third inch in diameter. It is set in a cast-iron yoke which extends back to the diaphragm; the latter rests upon the ends of the yoke. The whole is enclosed in a solid rubber case five inches long and two inches in diameter, resembling in appearance an ordinary telephone receiver. Three binding posts on the end are necessary; one end of each coil being connected to the middle post, and the other ends to the two outer posts. In addition to the receiver it is found convenient to use a "compensator" (mentioned below), to aid in the adjustment of the telephone.

Before the instrument is ready for use, three adjustments are necessary, namely: for equality of resistance, of inductance, and of magnetic effect of the coils. The latter is the most difficult to obtain and requires some skill on the part of the one testing the instrument. Inequality of magnetic effect is caused by the two coils not being exactly symmetrical on the bobbin. To compensate for this a small coil of six or eight turns is connected in series with one branch and placed by trial in the proper position near the bobbin. This coil is fastened firmly to the yoke by a screw before the rubber case is put on.

Equality of resistance and inductance is brought about by means of a compensator. This consists of sliding contact resistances and moveable mutual-inductance coils in series with each branch of the telephone. These are fastened with suitable adjusting screws upon a hard-wood frame seven by ten inches. The resistance is varied by the sliding contacts and the inductance varied by changing the relative position of the inductance coils. The adjustments are made once for all and the instrument is ready for use. When adjusted no sound is heard when an alternating electro-motive force is applied at the terminals of the 'phone (one terminal on the receiver and the other on the compensator).

In comparing a self-inductance with a standard, two independent balances must be made. The resistances of the parallel circuits must be made equal and the self-inductances must be made equal. The latter is effected by varying the standard self-inductance. To make the resistances equal, a non-inductive resistance box is included in the branch of least resistance. One of these balances does not depend upon the other (as is the case, for instance, in Maxwell's method of comparing a self-inductance with a capacity), and hence the double balance is much easier than it otherwise would be. If the divisions of the resistance box are not small enough, the final balance of the resistances may be made by means of the sliding contacts on the compensator. With very little practice this balance, as well as that for non-inductive resistances or for capacities, can be quickly obtained.

The advantages of using a differential telephone as described above for measuring a self-inductance are: (a) That the apparatus is portable and does not get out of order easily; (b) that great accuracy can be attained and the manipulation is not difficult; (c) that the heating of the circuits by the currents does not alter the self-inductance balance, and therefore that large electro-motive forces may be used; and (d) that only one standard is required; it is not necessary to know the resistances or the lengths of a bridge wire. The disadvantage is that the self-inductance of the standard must equal that of the coil to be measured. If, however, the self-inductance to be measured is smaller than the smallest inductance obtainable in the standard, a fixed standard may be placed in series with the unknown coil, and the sum of their self-inductances measured; and if the self-inductance to be measured is greater than the greatest inductance obtainable in the standard, a fixed standard may be placed in series with the variable standard. Thus the range of measurement may be increased indefinitely beyond the limits of the variable standard. These advantages apply equally well to the measurement of non-inductive resistances and of capacities.

In comparing non-inductive resistances, any slight inductance may be balanced by shifting the mutual inductance coils on the compensator. In measuring the resistance of an electrolyte it was found better, when possible, to vary the resistance in the electrolytic cell by shifting the electrodes, rather than to vary the known resistance by changing plugs; for in the former case the resistance, and, therefore, the sound in the receiver, varies continuously, and the minimum sound can be more easily detected. In comparing capacities any slight inequality of resistance or self-inductance in the branches does not affect the balance appreciably. Thus, in comparing capacities, the compensator may be dispensed with.

The following will indicate the accuracy of the instrument in the uses given above. The attempt was made to obtain data on its sensibility in ordinary laboratory measurements:

In a long series of determinations of self-inductances, ranging from 10 to 40 mille-henrys, the greatest deviation from the mean of any determination was not greater than 1-10 of 1 per cent of the inductance measured. The percentage error is smaller the larger the inductances compared. In measuring non-inductive resistance a series of determinations was made of resistances ranging from 1 ohm to 500 ohms, and the percentage deviations from the mean in each case plotted as ordinates of a curve. This is a smooth curve descending from 5-10 of 1 per cent for resistances under 10 ohms to 2-10 of 1 per cent for resistances between 200 and 500 ohms. For the determination of electrolytic conductivity, a cylindrical cell 8 centimeters high by 3 centimeters in diameter, was used; the electrolyte was a 10% solution of sodium chloride. The resistance of this cell was about 7 ohms. The percentage errors of resistance were smaller than those of wire resistances, and the greatest deviation from the mean of the calculated conductivity was 7-10 of 1 per cent.

The accuracy in the comparison of capacities is much greater than that obtained in any other measurement. For convenient and speedy comparison a continuously variable standard of large capacity is needed. From lack of such a condenser the comparison of capacities is rendered more difficult, and the data here obtained are quite limited. An air (parallel plate) condenser was used as a variable standard in addition to larger box condensers. By placing the air condenser in one branch of the telephone a capacity of .0002 microfarads was easily detected. In comparing capacities of .2 microfarads a change of either capacity by .0004 microfarads could be detected. This would indicate a probable error of 1-10 of 1 per cent. For speedy comparison of capacities by the differential telephone the design of a continuously variable standard, ranging from 0 to .1 microfarads, is needed.

COMPOUNDING OF ROTARY CONVERTERS.

By Joseph L. Burnham, B. S. (E. E.), 1899.

For railway and power service in which rapid fluctuations of load occur, it is desirable to furnish constant direct-current voltage at the bus bars or, if possible, at the motors.

Unlike in the direct-current generator, the direct-current voltage of a rotary converter supplied with constant alternating voltage cannot be changed by change in field strength, except a very small amount, due to internal inductance and resistance of machine, which is practically negligible. The ratio of A. C. to D. C. voltage being practically unchanged by changes in excitation, it is necessary to vary the A. C. voltage at the collector rings in order to vary the D. C. voltage. This is accomplished by using the same connections of series and shunt fields as for the ordinary compound-wound direct-current generator, in conjunction with reactance coils in the alternating circuit. The result is a compounding of the A. C. circuit, causing a rise in A. C. voltage at the collector rings and consequently a rise of D. C. voltage.

Since the speed is fixed by the frequency of the circuit, the resultant excitation for a given applied A. C. voltage must be sufficient to give the required counter E. M. F. If the field excitation is too low, sufficient wattless lagging current will flow in the armature to make up the difference by armature reaction; or if the field excitation is too great, wattless leading current in the armature will demagnetize the proper amount.

It is due to these wattless lagging or leading currents in the reactance that components of reactance voltage are respectively subtracted from or added to the line voltage.

The principal elements to be considered in the voltage of the system are: The generator voltage, the reactance voltage, lagging 90° from the current producing it, the voltage consumed by resistance and counter E. M. F. of the rotary converter or D. C. voltage.

Then if E equal induced generator voltage or, in a large system, constant bus-bar voltage, e equals D. C. voltage of rotary converter.

I equal energy current.

Iw equal wattless current (considered + lagging and − leading).

X equal total reactance of all apparatus in the circuit between constant potential point E and the D. C. brushes of converter.

r equal total resistance, same as for reactance.

E^2 equal $(e + Ir + Iwx)^2 + (Iwr - IX)^2$. (1)

Considering the A. C. voltage of converter as unity and all transformation ratios being reduced to unity values of E; e, C and Cw may be expressed in their equivalent direct-current values. X will then be $\frac{\text{total reactance drop at full load}}{\text{full load amperes}}$,

and r will be $\frac{\text{total resistance drop at full load}}{\text{full load amperes.}}$, expressed as above.

The voltage of generator and converter being fixed, and the resistance and reactance known, it remains to determine values of wattless current, Iw, for no-load and full-load conditions. The change in wattless current from no load to full load will determine the ampere turns in the series fields necessary to overcome armature reaction.

Suppose the converter armature has n conductors per pole and i amperes per D. C. circuit at full load. Then the armature ampere turns per pole at full load equal $\frac{ni}{2}$.

If $\frac{Iw\ (\text{no load}) - Iw\ (\text{full load})}{I\ (\text{full load})} = p$,

Ampere turns series field (full load) $= \frac{pnif}{2}$. (2)

Where f equals impedance factor, *i. e.*,

$$f = \frac{\text{A. T. field excitations}}{\text{A. T. per pole of arm. reaction}},$$

when the converter is driven at synchronous speed with A. C. end short-circuited.

Allowing one-third of the current to pass through a shunt to the series field for final adjustment, two-thirds of the current would be in the series field and the number of series turns would be

$$\frac{3pnif}{4I}.$$

From a no-load phase characteristic of the rotary converter, plotted to A. C. amperes in armature and ampere turns field, the ampere turns for series field may be found directly with sufficient accuracy. Also the ampere turns series field may be obtained from the synchronous impedance curve similarly plotted.

Having determined the change in wattless current from no load to full load, the voltage for intermediate and overloads may be obtained by substituting back in equation (1). The change in wattless current will be proportional to the change in load (approximately). Consequently, all of the quantities are known except e.

A curve plotted to values of e and load will be above a straight line passing through e at no load and e at full load, for intermediate loads, and below the straight line for overloads. This is similar to the direct-current generator compounding curve, but the voltage drops more rapidly for increasing overloads. If corrections are made for changes of saturation and wattless current caused by the voltage departing from the straight line, the corrected curve will lie somewhat closer to the straight line. A bend in the saturation curve will be reproduced with increased bend in an over-compounding curve. To obtain a closer approach to a straight line, all parts of the magnetic circuit should be working on a straight portion of their magnetic saturation curves. In order not to limit the voltage of the machine, some parts could be well below the "knee," and others above. For over-compounding, the increased magnet saturation from no-load voltage to full-load voltage should be cared for by additional series field ampere turns.

It will be found that for higher values of E or the voltage delivered to the converter, a smaller change in wattless current, or less reactance, will be required; but the wattless current necessary to reduce e, the D. C. voltage, to the desired value, will be greater. In addition to the advantage of less series field or reactance for higher values of E, is the greater stability or freedom from tendency to "hunting" when operating with lagging current; but the heating of armature conductors is greatly increased.

Heating of the armature conductors will be caused by the wattless component of current in addition to the difference of instantaneous values of alternating energy current and direct current.

Assuming a sine wave of alternating current, the sum of i^2r for instantaneous values of difference of alternating energy current and direct current is,

26% for six-phase converter,
37% for quarter-phase converter,
56% for three-phase converter

of the I^2r for direct or alternating current alone, *i. e.*, as generator or motor.

Therefore, to prevent the heating at no load from exceeding that at full load, the wattless current should not exceed

$\sqrt{.26} = 51\%$ for six-phase converter,

$\sqrt{.37} = 61\%$ for quarter-phase converter,

or $\sqrt{.56} = 75\%$ for three-phase converter, of full-load current.

Should the wattless currents found in the preceding calculations exceed the percentages of full-load current given above, the reactance in the circuit should be increased. The armature heating for a given compounding can thus be reduced by adding artificial actance to the circuit. For economical reasons the amount of reactance would be determined by minimum combined cost of reactive coils and converter armature, but in practice is limited on account of producing an increasing tendency to pulsation or hunting, if too great. The ideal conditions for ordinary operations seem to be with no-load lagging current giving maximum permissible armature heating, taking into account the all-day load curve. The possible amount of compounding, as well as line drop, without difficulty from pulsation, depends principally upon the uniformity of angular speed of the prime mover for a given combination of conditions.

The adjustment for best efficiency may be determined from the all-day load curve, by making the sum of copper losses in field and armature for loads with lagging current equal to the sum of same losses for loads with leading current. This, however, is of minor importance.

SIZE DIFFERENCES OF BOLTS AND NUTS FOR "V" AND STANDARD THREADS.*

By George R. Moore, Superintendent of Shops.

The writer has felt the need of a table giving size differences of bolts and nuts for "V" and standard threads, and has worked up the accompanying table.

This table shows at a glance the difference in size of any bolt and nut based on the depth of the thread (number of threads to the inch), regardless of the diameter of either. Having a bolt of any diameter, for any given thread, subtract the difference given in the table for that thread (or if the difference wanted is not given, it can be found by the rule) and it will give the size to which the nut is to be punched, drilled or bored. Having the size of the nut, add the difference to get the size of the bolt. This difference allows for a full thread for both bolt and nut, to the nearest 64th of an inch. In all tables which the writer has seen, this difference in size is based on the Standard, or U. S. thread, or on a given (standard) sized bolt and a given number of threads to the inch for that size only; *e. g.*, ¼-in., 20 threads; ¾-in., 10 threads; 3-inch, 3½ threads, etc., there being no table of sizes for the "V" thread, which is the one most commonly used. The further utility of such a table is shown when it is considered that the dimensions for such calculations are usually given in decimals, with which the average mechanic is not familiar; or, if he is, he will not take the time to reduce to a fraction of an inch the decimal given, but will make the hole in a ¾-in. nut (10 threads) ⅝-in. scant, or somewhere near ⅝-in.

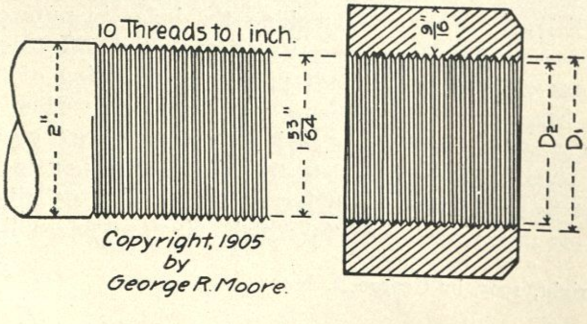
The difference given in the table is for "V" threads. For "Standard" threads, but three-fourths of this difference is to be considered.

Mr. Sellars recommends making the holes in nuts of such a size as to allow for 85% of a full thread, the difference (about 12%, or one-eighth) being made up by the crowding of the metal. This has been found to be very good practice. This allowance (which would be about one-eighth of the difference given in the table), if used, must be added to the given difference and the hole in the nut be made that much larger, there being no allowance in the table for the crowding of the metal. Such a table will be found useful wherever bolts and nuts are made or used, particularly in mathematical instrument factories and other establishments where a great many other than standard threads and sizes are used.

SIZE DIFFERENCES OF BOLTS AND NUTS FOR "V" AND STANDARD THREADS.

I No. Threads to 1 in.	II Depth of Thread Constant.	III Nearest 64th.	IV D_1-D_2, or Dif.
1	.866	55/64 = .859	1 47/64
2	.433	28/64 = .437	7/8
3	.288	18/64 = .281	9/16
4	.216	14/64 = .218	7/16
5	.173	11/64 = .171	11/32
6	.144	9/64 = .140	9/32
7	.124	8/64 = .125	1/4
8	.108	7/64 = .109	7/32
9	.096	6/64 = .093	3/16
10	.087	5/64 = .078	11/64
11	.079	5/64 = .078	5/32
12	.072	5/64 = .078	5/32
13	.066	4/64 = .062	9/64
14	.062	4/64 = .062	1/8
15	.058	4/64 = .062	1/8
16	.054	4/64 = .062	7/64
17	.051	3/64 = .046	7/64
18	.048	3/64 = .046	3/32
19	.046	3/64 = .046	3/32
20	.043	3/64 = .046	5/64

RULE: .866 divided by Pitch $\times$ 2 = $D_1 - D_2$.
For U. S. or standard threads take ¾ ($D_1 - D_2$).
$D_1 - D_2$ for "V" thread = 1.732 divided by Pitch.
$D_1 - D_2$ for U. S. or standard thread = 1.299 divided by Pitch.



AN INSULATOR TEST.

By Stanley D. Coffin, B. S. (E. E.), 1903.

High-tension transmission at the present time is receiving a great deal of attention in the engineering world. Its importance is indicated by the large amount of special work done in this line by some of the large electrical companies. Since results in high-tension work cannot be accurately prophesied, the data to be relied upon are obtained from tests made under the most adverse working conditions.

A test made by an electrical company to show the relative value of different types of insulators under very high voltage was on a line 800 feet long, situated near a railroad and a power house, so that smoke and dirt were nearly always present—a bad condition for high-voltage lines. The wires were No. 5 B. & S. (copper), placed 4 feet apart and supported by 42 insulators of various types. One hundred and twenty thousand volts was put on the line and kept there, most of the time, for a month; during which time observations were made of the line losses and the behavior of the line and insulators under the various conditions of the weather.

The first two weeks it rained nearly every day and the line was noisy and luminous. At night the brush discharge from both wire and insulators was nearly a foot long. Noise and glow first appeared at about 60,000 volts and increased rapidly as the voltage was raised. When it was raining, waves traveled back and forth along the wires between the poles at a high frequency and disappeared only when the voltage was lowered to about 60,000 volts. As the voltage was raised they appeared again at 96,000 volts and were strong enough at 120,000 to shake the poles and tug at the insulators on the building at the end of the line.

The first five poles were equipped with Locke's No. 329 porcelain insulators, and gave no trouble. There was a little noise and glow, which was confined to the head of the pin; but when the design was changed, placing the first petticoat as in the Stone & Webster, all noise and glow disappeared. Next on the line was Locke's No. 25 glass insulator. Four of this type were on iron pins with porcelain bushings and six were on dry wooden pins, but the result was apparently the same on the two pins. They made a loud buzzing sound and gave a great glow. It was necessary to replace many of them, as they were continually breaking.

Locke's No. 316 insulators were tried, mounted on iron pins with porcelain bushings, but proved to be too small for such a voltage, and after much trouble were replaced by one of Thomas' No. 60 porcelain, one of Richard Ginori's (Italian), four of Locke's No. 33 and four of Stone & Webster's No. 4.

Thomas' insulator was punctured, but the fault was in the material and not the design, which is good. The Richard Ginori, a fine white porcelain insulator, stood the voltage well. Locke's No. 337 and Stone & Webster's No. 4 are large types and gave no trouble. Other tests show the efficiency of these two types to be about the same. Stone & Webster's No. 4 is less complicated and weighs 24 lbs., while Locke's No. 337 weighs 32 lbs.

Muncie, Provo No. 0, Locke's No. 318 and Locke's No. 331 were tried, but all four types are evidently too small for such voltage. The Muncie, a good design, and Provo No. 0, are of Hemingray glass.

As a result of this test, and many others, an insulator has been designed called the Chesney Thomas, now manufactured by Thomas, which is a combination of the good qualities of many others. It has no static discharge and will stand 120 kilo volts, between an iron pin and the wire, under a shower of a ¾-inch stream of water. The material is porcelain. All tests show that porcelain is better than glass for high-voltage insulators, for when the glass breaks it goes all to pieces and allows the wire to drop. On the other hand, the porcelain simply punctures and after the insulator has broken down it offers just as good a support as ever.

It has also been demonstrated that thick porcelain is no better than thin. Two insulators the same size, one a half-inch in thickness and the other an inch, will break down at the same voltage.

SOME HINTS ON A CAMP OUTFIT.

By Winfield Holbrook, B. S. (C. E.), 1904.

Inasmuch as a great many graduates of technical schools commence their work in actual practice on surveying parties, the writer is of the opinion that a few hints concerning a camp outfit will be helpful.

The novice in camp life is liable to imagine that he must carry little baggage and, therefore, carry insufficient bedding. In tent life a good bed is a prime requisite, and the best equipment consists of a cot, mattress and three or four woolen blankets or quilts, with a large tarpaulin to keep them dry. Cotton blankets are not good, as they are cold and heavy.

In snowy weather the high-top waterproof shoes, which do very well in dry weather, furnish little protection against wet feet. To keep out melting snow, rubber shoes and German or felt socks are best, and are much warmer.

In high altitudes, woolen underclothing should be worn the year round; light weight in summer and heavy weight in winter. A cold rain at timberline might otherwise chill a man to the bone and result seriously. Corduroy and khaki make durable clothing for summer, and corduroy and woolen for winter time. Leather-lined jackets exclude the wind, and allow more freedom of movement than an overcoat.

Mosquito bar in summer and snow glasses in winter are articles which the beginner is liable to overlook, but which are very necessary. To keep out gnats, take a fine-mesh silk veiling, double it and shape it like a bag, leaving the bottom open. The ends may be gathered with rubber cords, so that one will fit around the neck and the other around the hat band. The brim will hold the veiling away from the face. Such a bar does not obstruct the sight and may also be used as a protection for the eyes and face against the glaring snow in winter.

Light leather gloves will protect the hands from insects in summer; but woolen mittens, or as a substitute light silk or woolen gloves worn inside a pair of leather gauntlet gloves, will be needed in winter.

A short time in camp will teach the novice what articles are really necessary for his comfort and what should be left behind next time.

In nearly every camp trip there are times of hardship, which cannot be prevented, even when foreseen. At such times a stiff upper lip and cheerfulness, even if a little forced, are the best outfit, till the tide turns for the better.

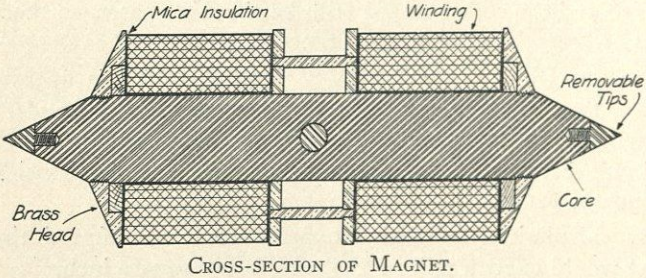
A LARGE ELECTROMAGNET FOR OPTICAL AND SURGICAL WORK.

By Harry E. Sovereign, Electrical Engineering, 1907.

The large number of men now employed about machines where flying splinters of iron are common has brought a new task before the oculist. Large ragged chips of iron or steel thrown from a lathe or other tool sometimes enter the eyeball, and can generally be taken out at once through the wound with the proper surgical instruments; but a tiny chip will sometimes be overlooked and may cause serious trouble. The oculist may, perhaps, test for the splinter with a magnetometer needle which is not delicate enough to detect so small a piece, and nothing is found. Magnets with small curved pole pieces, to be moved around under the eyelid and remove small splinters, have been made, but this type of magnet is but little used as it is apt to injure the eye.

Dr. Edmund C. Rivers, a prominent Denver oculist, having a great number of such cases, had made a large electromagnet of which the following is a description. The author is indebted to The Carstarphen Electric Company for the data and illustrations used in this article:

The core consists of a cylindrical Norway iron forging twenty-nine inches long and four inches in diameter, which weighs 110



Cross-section of Magnet.

pounds. Around this are wound two magnetizing coils of the proper number of turns to saturate the core when in series on the 220-volt power circuit, or when in parallel on the 110-volt direct-current circuit, either of which voltage is standard. The ends of the core are provided with conical pole pieces, the tips of which are removable in order that they may be sterilized, or tips of other shapes substituted. The angle of the pole pieces approaches that which would give the greatest concentration of magnetic force at the point, yet this must be much more acute than the proper angle in order to leave the operator's view unobstructed. A steel rod one and one-quarter inches in diameter passes through the center of this core at right angles to its length and is hung in a "U"-shaped support which revolves about a vertical axis. Two brass discs are slipped on this core, one on each side of the steel rod, which are kept at the proper distance apart by means of four short brass rods. On each end of the core is screwed a cast brass head ten inches in diameter. After mica insulation had been applied to the core and sides of the heads a winding space of twenty square inches was left on each bobbin. Three thousand, five hundred and twenty turns of number 14 D. C. C. magnet wire were wound on each bobbin, this being sufficient to practically saturate the core when 6 amperes flowed through the coils. One hundred and ten pounds of wire was required. Great care was taken in insulating the coil from the core and also the layers from each other, as the self-induction of this coil was quite a factor.

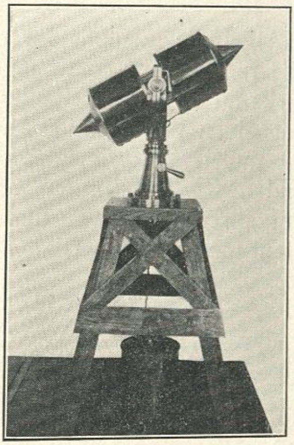
The magnet is mounted on an oak stand which makes the tip of the core, when the magnet is inclined at a small angle, level with a seated patient's eye; when more sharply inclined, it reaches the level of an operating chair, when the magnet may be used for removing steel bullets or other magnetic material lodged in any part of the body.

The brass parts of the instrument are machine finished and lacquered and the coils covered with hard rubber cases, so the whole presents a very handsome appearance.

The current is controlled by a rheostat, which is operated by the foot, thus allowing the operator the use of both hands. The foot switch is so made that all of the resistance is introduced into the circuit before the latter can be opened, thereby considerably reducing the arc due to self-induction.

By calculation and actual experiment it was found that the magnet would exert a pull of 150 pounds per square inch.

In diagnosis, the pole of the magnet is placed near the eye or part of the body in which a piece of iron is thought to be imbedded and a small current sent through the coils, when generally the patient can feel a dull pain due to the attraction for the particle. The current is then strengthened, and after an exposure of some minutes a bulging in the skin will be noticed when, after a careful incision, the piece is taken out by the magnet.



MAGNET AND STAND.

A remarkable case is on record in which this magnet extracted a steel pin from the foot where it had been lodged for over two years. Still another case is reported in which the magnet removed a steel sewing needle from a boy's foot when other methods had failed.

The successful use of this giant magnet in these two cases, in each of which careful dissection had failed to locate and remove the fragment of needle, is indicative of a new use to which the instrument may be applied.

SOME GRAPHIC METHODS FOR CALCULATING THE DEFLECTION OF BEAMS.*

By Milo S. Ketchum, C. E., Professor of Civil Engineering.

Introduction.—Algebraic methods for calculating the deflection of beams and the reactions of continuous beams are given in detail in standard works on applied mechanics. The graphic methods are, however, not given the attention that their elegance and simplicity merit. The underlying principles of the graphic method will be developed and a few applications of the method will be given in the following discussion. The discussion will be limited to beams with a constant moment of inertia.

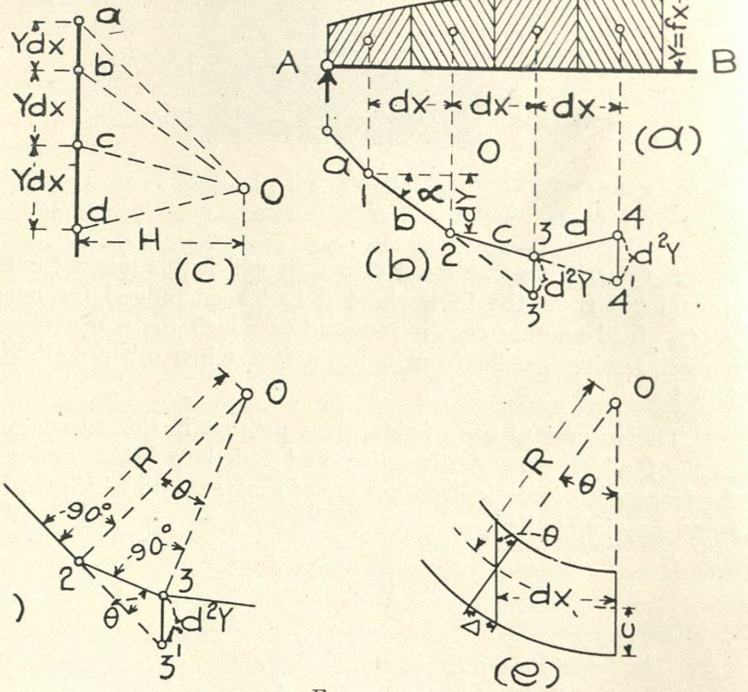


Fig. 1.

Graphic Equation of the Elastic Curve.—Load a simple beam with a continuous load represented by the equation $y = fx$, as in (a) Fig. 1. Assume that each differential load, $y\,dx = fx\,dx$, acts through its center of gravity. Now construct a force polygon as in (c) and an equilibrium polygon as in (b) Fig. 1.

Now, in (b) the tangent of the angle between any side of the equilibrium polygon and the axis of X is $\tan a = \frac{dy}{dx}$. If the string bo in (b) is produced until it cuts the vertical line through 3, it will cut off the intercept $3\text{-}3^1$, which is the difference between two consecutive values of dy and therefore equals d^2y.

Now, it has been proved* that the moment of the force acting through point 2 in (b) about point 3, is equal to the intercept $3\text{-}3^1$ multiplied by the pole distance H, is equal to $3\text{-}3^1 \times H = d^2yH$. But the moment of the differential load $fx\,dx$, which acts through point 2, about point 3, is $fx\,dx^2$, *and*

$$fx\,dx^2 = d^2yH, \text{ and}$$

$$\frac{d^2y}{dx^2} = \frac{fx}{H}. \qquad (1)$$

It is evident that (1) is the differential equation of the equilibrium polygon in (b).

Now, if the loading is taken so that $y = fx = M$, where M represents the bending moment at any given point x, due to a given loading, the equation for the equilibrium polygon becomes

$$\frac{d^2y}{dx^2} = \frac{M}{H}. \qquad (2)$$

From mechanics we have the relation that

$$\frac{d^2y}{dx^2} = \frac{M}{EI}, \qquad (3)$$

which differs from (2) only in having EI substituted for H, E being the modulus of elasticity and I the moment of inertia of the given beam.

* "The Design of Steel Mill Buildings," by Milo S. Ketchum, C.E., Engineering News Publishing Company, 220 Broadway, New York City.

This relation may be deduced directly as follows: In (d) Fig. 1, let equilibrium polygon 1-2-3 represent the neutral axis of a beam as in (a), the points 1, 2 and 3, being at a distance dx apart. The distortion will be assumed to be so small that $dl = dx$. Now, the triangle 2-O-3 may be taken as equal to triangle 3-2-3[1] for small distortions, and

$$O\text{-}2 : 2\text{-}3 :: 2\text{-}3 : 3\text{-}3^1;$$

but O-2 equals R, 2-3 equals dx, and 3-3[1] equals d^2y; and, therefore,

$$\frac{d^2y}{dx^2} = \frac{1}{R}. \tag{4}$$

Now, in a beam as in (e) Fig. 1, the stresses at any point in the beam will vary as the distance from the neutral axis, and from similar triangles we have

$$R : dx :: c : \Delta, \text{ and}$$
$$R\,\Delta = cdx. \tag{5}$$

Now, if S is the fiber stress on the extreme fiber, and E is the modulus of elasticity, we have

$$\Delta : S :: dx : E$$
$$\Delta E = Sdx; \tag{6}$$

and, solving (5) and (6) for R, we have

$$RS = Ec.$$

But from the common theory of flexure we have $Mc = SI$, and substituting

$$R = \frac{EI}{M}. \tag{7}$$

Substituting the value of R in (7) in (4) we have

$$\frac{d^2y}{dx^2} = \frac{M}{EI}. \tag{3}$$

The preceding discussion gives the following simple graphic method for constructing the elastic curve of a beam, simple or continuous:

Construct the bending moment polygon for the given loading on the beam. Load the beam with this bending moment polygon, and with a force polygon having a pole distance equal to EI, construct an equilibrium polygon; this polygon will be the elastic curve *of the beam.* It is not commonly convenient to use a pole distance equal to EI, and a pole distance H is used, where NH equals EI; the deflection at any point will then be equal to the measured ordinate divided by N.

SIMPLE BEAMS.—The simple beam will be considered when loaded with concentrated and uniform loads, using both algebraic and graphic methods.

Algebraic Method—Concentrated Load at Center of Beam.—The simple beam in (a) Fig. 2, is loaded with a load P at the center. The bending moment diagram is shown in (b) and the beam is loaded with the bending moment diagram in (c) Fig. 2.

To find the equation of the elastic curve take moments of the forces to the left of a point at a distance x from the left support, and

$$-EIy = \frac{PL^2x}{16} - \frac{Px^4}{12}, \text{ and}$$

$$48\,EIy = P(4x^3 - 3L^2x). \qquad (8)$$

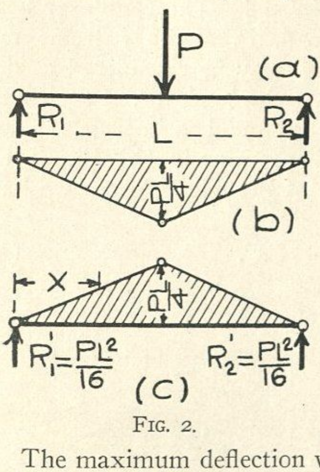


FIG. 2.

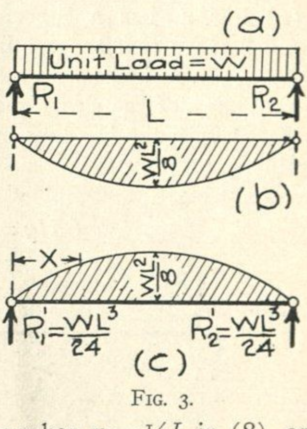


FIG. 3.

The maximum deflection will occur when $x = \frac{1}{2}L$ in (8), or it may be found by taking moments of forces to left of $x = \frac{1}{2}L$ to be

$$\Delta = \frac{PL^3}{48EI}. \qquad (9)$$

Beam Uniformly Loaded.—The simple beam in (a) Fig. 3, is loaded with a uniform load of w per lineal foot. The bending moment parabola is shown in (b), and the beam is loaded with the bending moment parabola in (c) Fig. 3. To find the equation of the elastic curve, take moments of forces to the left of a point at a distance x from the left support.

The equation of the bending moment parabola with the origin of co-ordinates at the left support is $y = \frac{1}{2}PLx - \frac{1}{2}Px^2$, the area of a segment of the parabola is $A = \frac{1}{4}wLx^2 - 1\text{-}6\,wx^3$, and the center of gravity measured back from x is

$$-X = \frac{x(2L - x)}{6L - 4x}.$$

Taking moments of forces to the left of a point x, and reducing, we have

$$24\,EIy = w(-x^4 + 2Lx^3 - L^2x). \qquad (10)$$

The deflection is a maximum when $x = \frac{1}{2}L$, and may be found directly by taking moments, or may be found from (10), and is

$$\Delta = \frac{5}{384}\frac{wL^4}{EI}. \qquad (11)$$

CANTILEVER BEAM—*Concentrated Load.*—The cantilever beam in (a) Fig. 4, has a concentrated load, P, at its extreme end. It will be seen that the cantilever beam may be considered as one-half of a simple beam with a span, $2L$, and a load, $2P$, at the center. The equation of the elastic curve may be found as in Fig. 2. Load the beam with the bending moment diagram as in (b) Fig. 4, and considering the cantilever as one-half of the simple beam we have, after reducing,

$$6EIy = 3PL^2x - Px^3. \qquad (12)$$

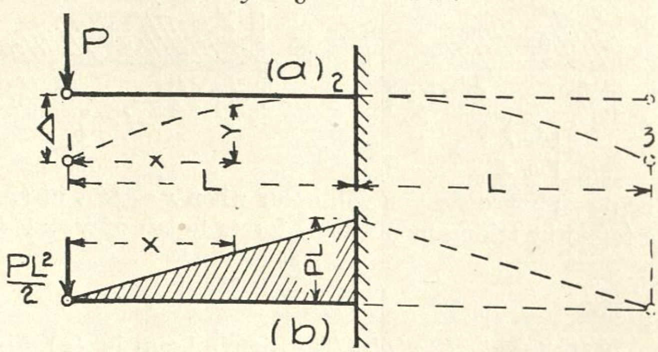


FIG. 4.

The maximum value of Δ is equal to y when x equals L, and

$$\Delta = \frac{PL^3}{3EI}. \qquad (13)$$

To find the maximum deflection we may take the moment of the entire bending moment parabola about the point 1, and

$$EI\Delta = \frac{PL^2}{2} \times \frac{2}{3} ;$$

$$\Delta = \frac{PL^3}{3EI} .$$

This method of finding the maximum deflection of a cantilever beam is the one to use in calculations, and will be used in the solution of the problem of the transverse bent.

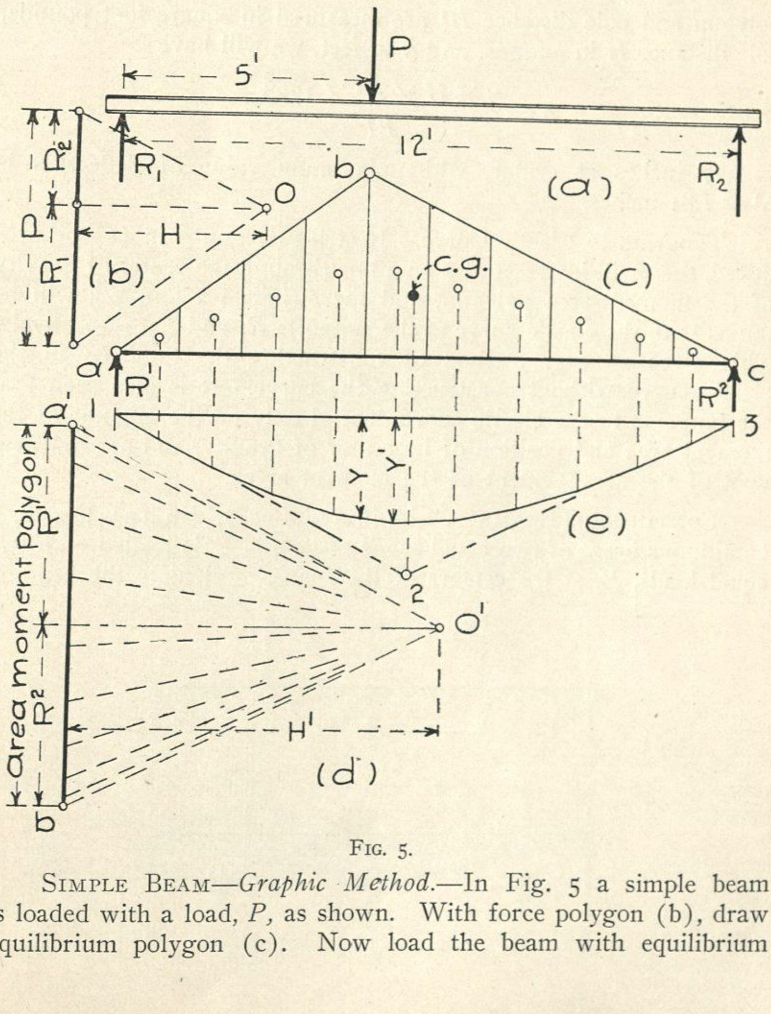


FIG. 5.

SIMPLE BEAM—*Graphic Method.*—In Fig. 5 a simple beam is loaded with a load, *P,* as shown. With force polygon (b), draw equilibrium polygon (c). Now load the beam with equilibrium polygon as in (c), divide the area of the equilibrium polygon into segments, which are treated as loads acting through their centers of gravity. Construct force polygon (d) and draw equilibrium polygon (e).

Now, the deflection at any point having an ordinate y in (e) will be, if proper scales are used,

$$\Delta = \frac{y \times H \times H^1}{EI} .$$

In Fig. 5, if P equals 5,000 lbs., and the area of the equilibrium polygon and pole distance H^1 are measured in square-foot pounds, pole distance H in pounds, and y in feet, we will have

$$\Delta = \frac{y \times H \times H^1 \times 1728}{EI}$$

$= 1.77$ inches at center, while maximum value of deflection is $\Delta^1 = 1.81$ inches.

Tangents to Elastic Curve.—If strings 1 and 3 in (e) be produced, they will intersect at 2 on a line through the center of gravity of the moment-area polygon, and the strings 1-2 and 2-3 will be tangents to the elastic curve at the supports R_1 and R_2, respectively. This gives an easy method of constructing the tangents to the elastic curve without constructing the curve. It is also seen that the tangents to the elastic curve depend only on the amount of the moment area and position of its center of gravity, and are independent of the arrangement of the moment areas.

CONTINUOUS BEAMS—*Concentrated Loads.*—In (a) Fig. 6, a continuous beam of two equal spans of length, L, is loaded with two equal loads, P, at the centers of the spans. Calculate the bending

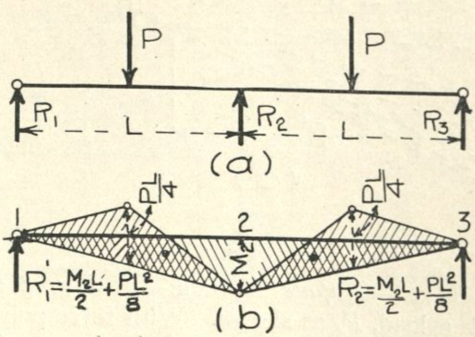


FIG. 6.

moments and load a simple beam with a span equal to $2L$, with the bending-moment diagrams due to P in each span, and with the negative bending-moment diagram due to the reaction R_2. Then to find M_2, the bending moment at 2, take moments of forces to the left of 2, and

$$\frac{M_2L^2}{2}+\frac{PL^3}{8}-\frac{M_2L^2}{6}-\frac{PL^3}{16}=0;$$

$$M_2=-\frac{3}{16}PL.$$

To calculate R_1 take moments in (a) about 2, and

$$R_1L-\frac{PL}{2}-M_2=0;$$

$$R_1=\frac{5}{16}P=R_2, \text{ and}$$

$$R_2=\frac{11}{8}P.$$

Beam Uniformly Loaded.—In (a) Fig. 7, a continuous beam of three equal spans of length, L, is loaded with a uniform load equal to w per foot. Calculate the bending moments due to a uniform load of w on each span, and load a simple beam of span $3L$ with the posi-

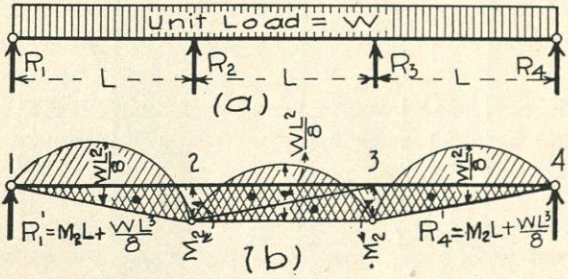


FIG. 7.

tive bending-moment diagrams due to load w, and with the negative bending-moment diagrams due to the reactions R_2 and R_3. The bending moment M_2 is equal to M_3. Now the deflection of the beam is zero at 2 and 3, and the bending moments must, therefore, be zero at these points. Taking moments of forces to the left of 2, we have

$$M_2L^2+\frac{wL^4}{8}-\frac{wL^4}{16}-\frac{M_2L^2}{6}=0;$$

$$M_2=-\frac{wL^2}{10}=M_3.$$

To calculate R_1 take moments about 2 in (a), and

$$R_1L - \frac{wL^2}{2} + M_2 = 0;$$

$$R_1 = \frac{4}{10} wL = R_4;$$

$$R_2 = R_3 = \frac{3}{2} wL - \frac{4}{10} wL = \frac{11}{10} wL.$$

Transverse Bent.—The problem of the calculation of the point of contra-flexure in the columns of a transverse bent—the algebraic solution of which is given in Chapter XI of "Steel Mill Buildings"—will now be solved by the use of moment areas. The nomenclature in Fig. 8 is the same as in "Steel Mill Buildings." It is assumed that the deflection at points b and c are equal

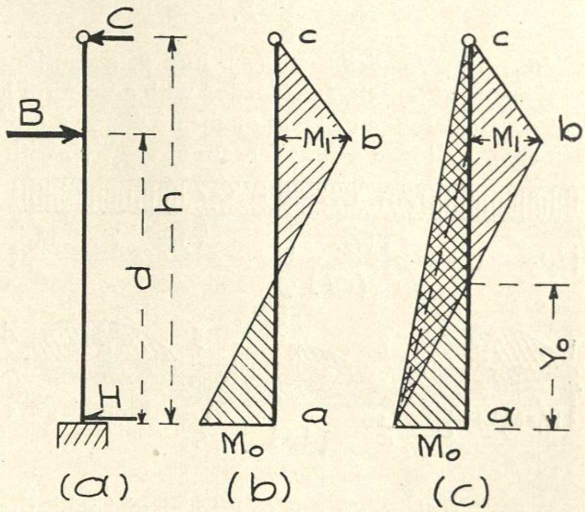


Fig. 8.

In (b) Fig. 8, the deflection at b from the tangent at a is found by taking moments of the moment areas below b to be

$$EI\Delta = \frac{M_0 d}{2} \frac{2}{3} d - \frac{M_1 d}{2} \frac{d}{3};$$

$$\Delta = \frac{2M_0 d^2 - M_1 d^2}{6EI}. \qquad (14)$$

The deflection at c from the tangent at a is found by taking moments of moment areas below c to be

$$EI\Delta^1 = \frac{M_0 d}{2}\left(h - \frac{d}{3}\right) - \frac{2M_1(h-d)^2}{6} - \frac{M_1 d}{2}(h - 2/3d)\,;$$

$$\Delta^1 = \frac{M_0(3dh - d^2) - M_1(2h^2 - hd)}{6EI}\,. \qquad (15)$$

But Δ is equal to Δ^1 by hypothesis, and equating (14) and (15) we have

$$2M_0d^2 - M_1d^2 = M_0(3dh - d^2) - M_1(2h^2 - hd)\,;$$

transposing,

$$M_0(3hd - 3d^2) = M_1(2h^2 - hd - d^2). \qquad (16)$$

Now in (c) Fig. 8, it will be seen that $M_0 : M_1 :: y_0 : d - y_0$, and

$$M_0(d - y_0) = M_1 y_0. \qquad (17)$$

Solving (16) and (17) for y_0, we have

$$y_0 = \frac{d}{2}\,\frac{(2h + d)}{(h + 2d)}\,, \qquad (18)$$

which is the same value as was found by algebraic methods in "Steel Mill Buildings."

Reactions of Simple Draw Bridges.—The preceding methods are not adapted to the solution of problems involving moving loads, as in draw bridges. The following method, which is an application of curved influence lines, is quite simple in theory and application, although requiring considerable labor in preparing the diagrams. The solution will first be explained and a proof given later:

Draw Bridge With Three Supports.—In Fig. 9 a continuous beam with spans L_1 and L_2 is loaded with concentrated moving loads represented by P_1 and P_2, as in (a).

In (b) load a simple beam having a span $L_1 + L_2$ with a bending-moment polygon due to the reaction R_2 (the value of R_2 is unknown, and any convenient load will do).

Divide the bending-moment diagram into segments, construct a force polygon as in (d) and draw an equilibrium polygon as in (c) Fig. 9, assuming that the segments are loads acting through their centers of gravity.

The pole distance H may be taken as any convenient length, and the pole O may be taken at any point [in (c) the pole has been selected to bring the closing line horizontal for convenience only].

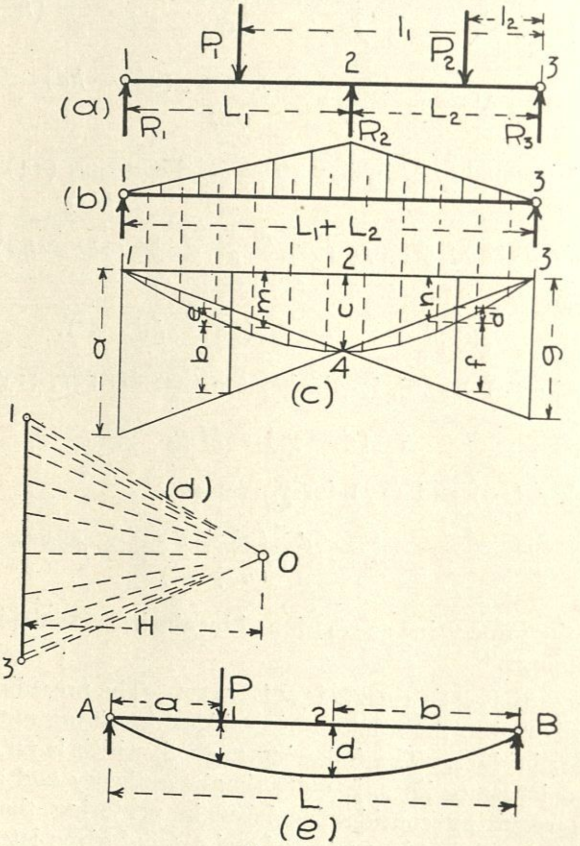


FIG. 9.

Then in (c) $$R_1 a = P_1 b - P_2 d, \text{ and}$$

$$R_1 = \frac{P_1 b - P_2 d}{a}\,; \tag{19}$$

$$R_2 c = P_1 m + P_2 n, \text{ and}$$

$$R_2 = \frac{P_1 m + P_2 n}{c}\,; \tag{20}$$

$$R_3 g = - P_1 e + P_2 f, \text{ and}$$

$$R_3 = - \frac{P_1 e + P_2 f}{g}\,. \tag{21}$$

Proof.—The ordinates to the equilibrium polygon in (c) are proportional to the ordinates to the true elastic curve of the beam in (b) when it is loaded with a given load at 2.

Now in (e) Fig. 9, if the deflection at 2 due to a load P at 1 is d, then if the load P be moved to 2, the deflection at 1 will be d. This can be proved by calculating the bending moments at 2 and 1 for the conditions, since the deflections are directly proportional to the bending moments. With P at 1, the bending moment at 2 is $\frac{Pab}{L}$; and with P at 2, the bending moment at 1 is $\frac{Pba}{L}$, and the proposition is proved.

Now in (c), if the deflection due to a load unity at 2 is m at P_1, then the deflection at 2 due to a load unity at P_1 will be m. If load R_2 is applied at 2, the work done in making the elastic curve pass through 2 will be R_2c; while the resistance due to a load P_1 will be P_1 times the deflection at 2 due to the load P_1, which is equal to P_1m. In like manner the resistance due to P_2 will be P_2n, and

$$R_2c = P_1m + P_2n, \text{ and}$$

$$R_2 = \frac{P_1m + P_2n}{c}. \qquad (20)$$

To find R_1 take moments about 3 in (a), and

$$R_1 \ (L_1 + L_2) + R_2L_2 - P_1l_1 - P_2l_2 = 0,$$

and from similar triangles in (c)

$$R_1a + R_2c - P_1(m + b) - P_2(n - d) = 0. \qquad (22)$$

Substituting the value of R_2 from (20) in (22), we have

$$R_1a = P_1b - P_2d;$$

$$R_1 = \frac{P_1b - P_2d}{a}. \qquad (19)$$

Since $R_1 + R_2 + R_3 = P_1 + P_2$,

$$R_3 = -\frac{P_1e + P_2f}{g}. \qquad (20)$$

For uniform loads the areas covered by the loading will be used in place of the ordinates.

Draw Bridge With Four Supports.—To find the reaction at R_2 in Fig. 10, proceed as follows: With a load represented by the triangle 1-2-4, construct a force polygon (not shown) and draw an equilibrium polygon passing through *m-n-o-p*. Now, with a load represented by the triangle 1-3-4, construct a force polygon (not shown) and draw an equilibrium polygon passing through *m-o-p*. The method of drawing an equilibrium polygon through three points is explained on page 31 of "Steel Mill Buildings."

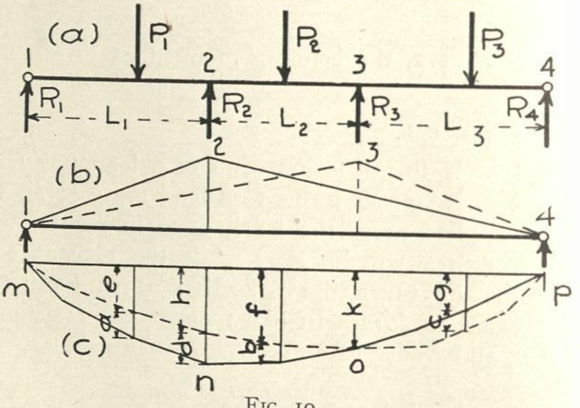


FIG. 10.

Then in (c) Fig. 10,

$$R_2 d = P_1 a + P_2 b - P_3 c, \text{ and}$$

$$R_2 = \frac{P_1 a + P_2 b - P_3 c}{d}. \quad (23)$$

R_3 may be found in a similar manner by drawing an equilibrium polygon for a load, 1-3-4, through point *n*.

When R_2 and R_3 have been obtained, the reactions R_1 and R_4 can most easily be obtained by algebraic moments.

Proof.—With the load, 1-2-4, and full line deflection curve we have, as in the case of three supports,

$$R_2(d + h) = - R_3 k + P_1(a + e) + P_2(b + f) + P_3 g. \quad (24)$$

And with the load, 1-3-4, and dotted line deflection curve we have, in like manner,

$$R_3 k = - R_2 h + P_1 e + P_2 f + P_3(c + g). \quad (25)$$

Subtracting (25) from (24) we have

$$R_2 d = P_1 a + P_2 b - P_3 c;$$

$$R_2 = \frac{P_1 a + P_2 b - P_3 c}{d}, \quad (23)$$

which is the equation of which proof was required.

BUILDING STONES.

By R. D. George, M. A., Professor of Geology.

OUTLINE.

Building Materials in General—Essential Qualities of Building Stones.

1. Strength.
   - (*a*) Factors determining the strength of a stone and the permanence of its strength—
     - (1) Composition,
     - (2) Texture,
     - (3) Structure,
     - (4) Mode of aggregation.
   - (*b*) Stresses considered.
2. Durability.
   - Agencies of disintegration and decay:
   - (*a*) Mechanical—
     - (1) Temperature-changes,
     - (2) Water,
     - (3) Wind,
     - (4) Mechanical wear in duty.
   - (*b*) Chemical—
     - (1) Water,
     - (2) Atmospheric gases,
     - (3) Organic acids, etc.
3. Workability.
   - (*a*) Quarrying,
   - (*b*) Dressing,
   - (*c*) Polishing and decorative working.
4. Color and Fashion.

Building Materials in General.

The common building materials may be classed as natural and artificial. To the first class belong wood, stone and raw clay; to the second, brick, cement and iron. It is clear to every observer that the consumption of the forest timbers of the United States far outruns the supply by regrowth. It is evident, therefore, that with a rapidly growing population and a rapidly decreasing timber supply, there must come an increasing use of stone and artificial building materials. Of all building materials, stone is best suited to the main structural features of large buildings and great public works, because it alone has the qualities of strength, durability, and dignity of appearance so generally sought in the erection of such structures. But many varieties of building stone are well adapted to the building of residences. And, for the laying of foundations, whether for buildings or for bridges and other public works, stone will probably continue for some time to hold first place among building materials.

Essential Qualities of Building Stones.

The essential qualities of building stones are: 1. Strength, 2. Durability, 3. Workability, 4. Color and beauty.

1. Strength.

The strength of a stone is measured by its ability to withstand stresses. A stone in a wall is subjected to strains of various kinds. Of these, the most important are the crushing, the tensile, the transverse and the shearing stresses.

(*a*) *Factors Determining the Strength of a Stone and the Permanence of its Strength:*

(1) Composition,
(2) Texture,
(3) Structure,
(4) Mode of aggregation.

(1) Composition.—The different minerals of which building stones may be composed vary widely in hardness and resistance to crushing force. For example, quartz is harder and has a higher crushing strength than calcite or feldspar. It is harder, but has a lower crushing strength than hornblende. Again, different minerals have different coefficients of expansion under changes of temperature; and the stresses resulting from differential expansion and contraction are more important in a rock composed of several minerals than in a rock composed of only one. Some minerals, such as calcite and feldspar, have very pronounced cleavage; while others, like quartz, have little or none. Cleavage renders a mineral weaker in certain directions than in others.

The solubility of the materials of a rock is an important factor in the permanence of its strength. This is particularly true in the matter of the cementing material in sandstones and other clastic rocks, where the weakening or removal of the bond between the grains would leave a crumbling mass.

(2) Texture.—Other things being equal, coarse-textured rocks are weaker than fine-textured rocks of the same composition. There is less interlocking of the component grains, more unoccupied space, and the contact planes between the minerals are distributed in fewer directions. The degree of porosity has an important bearing on the strength of a rock, and will be discussed more fully in another place.

(3) Structure.—The structural feature of most importance in building stone is lamination. In igneous rocks such as granite, lamination may be due to:

1. Arrangement of the component minerals with their broader faces parallel.

2. The segregation of the component minerals in parallel bands.

3. Pressure and shearing, resulting in fissility or cleavage.

In sedimentary rocks the lamination is generally parallel to the bedding planes, and may be due to short pauses in the deposition of the rock, to slight changes in the composition, and to difference in texture of the material of the rock.

Stones showing a directional structure from any of these causes split more readily in one direction than in another. The ratio of absorption of water, the coefficient of expansion, and the solubility, are unequal in the different planes. Such stones are stronger and weather better when laid with their lamination planes in a horizontal position.

(4) Modes of aggregation of the grains of the rock.—There are three common modes of aggregation of the grains or component parts of rocks:

1. Chemical.
2. Crystal.
3. Cementation.

The chemical aggregation is exemplified by compact, non-granular limestones and by non-crystalline igneous rocks. The mass may be called amorphous or homogeneous. There are no directions of unequal strength or liability to disintegration. Granites are rocks thrusts are proportionately greater from a single grain of 10 cubic centimeters than from ten grains of one cubic centimeter promiscuously arranged. The strain in the latter case is more equally distributed and, therefore, less destructive. For this reason fine-grained rocks suffer less than coarse.

The coefficient of lineal expansion of a mineral grain is different in the direction of the different crystal axes. Thus, quartz expands five and one-half times as much in the direction of the vertical axis as in a direction at right angles to that axis. Hornblende expands ten times as much in the direction of one of its axes as in that of another. These unequal expansions create similarly unequal stresses in the different directions.

A porous rock will probably suffer less from this force than will a compact one of the same composition, owing to the fact that a part of the expansion will be accommodated by the intergranular spaces. On the other hand, the area of intergranular contact is less in the porous rock, and consequently the work to be accomplished in separating the grains is less. In some parts of the United States the daily and seasonal range of temperature is very great, and changes are often very rapid. The particles of a stone are almost constantly acted on by this resistless force of expansion and contraction. The effects are much more marked on the south and west sides of buildings than on the north and east, owing to the fact that these sides are exposed to the sun during the hottest part of the day, and the changes of temperature are greater than on the other sides.

Stone is a poor conductor of heat, and under the influence of a midday sun the outer surface may be brought to a high temperature before the opposite side of the block has felt the effect of the sun. This causes a differential expansion which tends to weaken the stone. The north wall, not getting the direct rays of the sun, heats up more slowly and uniformly, and the resulting differential strain is much less. In winter the inside surface of a wall may have a temperature of 70° F. while the outside may be at — 30°. The effects of this rapid and intense surface heating are seen in the great talus streams of thin concavo-convex flakes and plates of rock which cover the slopes of many of our western mountains. A particularly good example of this is to be seen in the Dolores peaks of Colorado. "Shelling" of the surface of rocks is a common phenomenon, and is due, in large measure, to expansion and contraction from surface heating. E. R. Buckley in "Building and Ornamental Stones of Wisconsin," page 19, says that in many of the limestone quarries of Wisconsin thin beds five to six inches in thickness, when first exposed to the summer's sun, become heated entirely through and arch up on the quarry floor, and generally break so as to be useless. In certain parts of India the quarrymen build a fire on the floor of the granite quarry, and, as the fire is moved slowly over the surface, a slab of stone of uniform thickness splits away from the underlying rock. The thickness depends upon the depth the heat penetrates, but slabs five to six inches in thickness and several hundred square feet in area are taken up in this way. The splitting is independent of the lamination of the rock*. A familiar method of breaking large boulders in this country is to build a fire over them, and, when they become intensely heated, dash cold water over them. In large fires, stone walls may become intensely heated. If water is turned on the hot stone, it splits in layers parallel to the outer surface. Under such conditions granite probably suffers most and sandstone least of the common building stones. In the matter of durability of building stones, when subjected to such heat tests as the burning of a large building, authorities differ widely, but there is a measure of agreement on the point that granite is about the least fire-proof of the common building stones. Limestones, dolomitic limestones and marbles suffer comparatively little up to a temperature of 900°-1000° F., providing they are not suddenly cooled. Above this temperature they are likely to be changed to quicklime, and slacked when exposed to moisture. The behavior of sandstones under similar tests is usually good, though sudden cooling with water seems to cause a greater degree of disintegration than in the case of limestones. The fire tests made by Winchell† on the Minnesota building stones would seem to place the sandstones and limestones in about the same rank. But it is open to question whether the sandstones tested—the Potsdam, the St. Croix and the Jordan—as fairly represent sandrock building stones in general, as the limestones tested—the St. Lawrence, the Shakopee, the Galena and the Trenton—represent limerock building stones in general.

(2) Water.—As an abrading agent, water has very little effect upon the stones in the walls of buildings. River waters laden with sediments may, in time, cause appreciable wear on bridge foundations, but even here, except under rare conditions, the results are unimportant. But water within the stone may be the most powerful agent of mechanical disintegration to which building stone is

* H. Warth, "Quarrying of Granite in India," *Nature*, June 17, '95.
† "Geology of Minnesota," Vol. I, pp. 185, 196-203.

(4) Mechanical wear in floors, steps, etc.—This is an important consideration in stones used for floors and steps. Of the commoner building stones, granite and quartzite are most resistant. The wearing qualities of sandstones will depend upon the cement between the grains and the strength of the bond it affords. Those having a siliceous cement are most durable, and especially if the cementing silica is united with the grains by crystal growth. Limestones are, as a rule, unsatisfactory floor and step stones, owing to their softness. Some siliceous limestones wear well, and the nongranular varieties outlast the granular.

(*b*) *Chemical Agencies:*

The principal agencies of chemical disintegration are: 1. The normal constituents of the atmosphere—nitrogen, oxygen, carbon dioxide and water vapor. 2. The impurities, or accidental constituents—ammonia; nitric, sulphurous and sulphuric acids. 3. The compounds formed by reactions between members of groups one and two, and the constituents of the stone. 4. Organic compounds derived chiefly from plant life.

Of the first group, oxygen, water and carbon dioxide are important. For convenience their work is frequently referred to under the headings: Oxidation, hydration and solution, carbonation. But it is not likely that any one of these processes would be important without one or more of the others, and it may be doubted whether, under natural conditions, any one of these goes on separately. The chemical break-down of a rock is a very complex process, involving many reactions and interactions. In a paper such as this it is possible to indicate only a few of the more evident changes which take place in the minerals of which building stones may be composed.

The work of water is manifold. But perhaps it is as a medium through which other chemical reagents may work, that water plays its most important part in the chemical break-down of rocks. From the air it gathers oxygen, carbon dioxide, sulphuric and nitric acids. From the soil and disintegrating rocks it derives organic acids and mineral salts. All these are carried by it to the rocks with which it comes in contact. But this is, in part, mechanical, and in part chemical. Solution and hydration are other important phases of the work of water.

As a solvent, pure water has very little effect upon rock-making minerals. But the waters which come into contact with building stones are rarely pure. They have become dilute acids, and their solvent power is greatly increased.

Limestones and marbles, sandstones with ferruginous and calcareous cement, the feldspars and ferromagnesian minerals of granites and other igneous rocks are most readily attacked. Ordinary pure, compact, nongranular limestones are not so seriously affected. The texture prevents the acidulated waters from penetrating far into the stone before evaporation checks its course. But the porous, crystalline granular limestones and sandstones offer more favorable conditions for the work of solution. The water penetrates the intergranular spaces, dissolves or weakens the bond between the grains, and prepares the way for crumbling.

Under ordinary conditions carbon dioxide is probably the most important aid water has in its work of solution. This is due to its universal presence, and to its very general, though slow, solvent action upon the rock-making minerals. In the break-down of the feldspars, the carbon dioxide unites with the potassium, sodium and calcium oxides, forming the corresponding carbonates which are largely carried away in solution. At the same time, water aluminum oxide and part of the silica unite, forming kaolin. The remaining silica may be separated and deposited as quartz, or it may be dissolved and carried away by the waters holding the alkali carbonates. Feldspars which have undergone such changes are said to be kaolinized. They have lost their luster, hardness and largely their strength, and are ready to break down into kaolin or clay. The fracturing resulting from expansion and contraction in response to temperature changes is a great aid in the process of chemical change.

As a rule, the dark minerals—hornblende, biotite and pyroxene—of the granite break down before the feldspars and quartz. In this process many secondary minerals are formed and may completely fill the space once occupied by the dark minerals. Under certain conditions the new minerals formed require more space than the original, and so mechanical strain results from their formation, but in most cases a part of the constituents will be removed in solution. No matter what the process may be, the result is generally the weakening of the stone.

Hydration, apart from oxidation and solution, is probably of little importance except where long-continued saturation occurs. So far as building stones are concerned, only those used in foundations are likely to suffer. Even here, the mechanical effects of hydration are more important than the chemical.

The oxidation and hydration of the iron-bearing minerals, such as iron carbonate, pyrite and the ferromagnesian minerals of the granites and other crystalline rocks, often result in objectionable discoloration, and occasionally in some disintegration, though it is rarely important. Under certain conditions the new iron minerals formed are deposited as a cement between the grains of the rock.

Sulphuric, sulphurous and nitric acids are present in appreciable amounts only in the atmosphere of large cities where the consumption of coal is large. Careful tests were made on scrapings from the partially disintegrated surface of the Bedford, Indiana, limestone in the older buildings of the University of Chicago. Traces of sulphur were found in the scrapings from the outer eighth-of-an-inch of the stone. One quantitative analysis has been completed, and others are under way. The material analyzed was taken from a building which has stood ten or eleven years, and the results show 2.33 per cent of sulphuric anhydride—an amount almost incredibly large. Assuming that the anhydride is combined with calcium oxide and water in the form of calcium sulphate, 5.01 per cent. of the surface material is gypsum. In the change from $CaCO_3$ to $CaSO_4.2H_2O$, 100 parts of $CaCO_3$ will yield 172 parts $CaSO_4.2H_2O$. Making no allowance for loss by solution in the process of change, it is evident that approximately 3 per cent of the surface of the original limestone has been converted into gypsum.

Sixteen analyses of the Bedford stone recorded by Hopkins and Siebenthal* show no trace of sulphur.

A microscopic examination showed that considerable intergranular matter had been carried away by solution, but it was impossible to determine satisfactorily the effective agency. It was found that the depth to which this disintegration had gone was by no means proportional to the time of exposure. Comparatively little difference could be observed between the depth of surface weathering in the oldest buildings and that on those one-third the age. It was, however, quite apparent that the mode of dressing the stone and its position in the building were important factors in determining the rate of surface disintegration. The tooth-chiseled surfaces in horizontal position had suffered more than any others. This was no doubt due to the shattering of the surface in dressing, and to the more favorable attitude of the stone for absorbing and retaining moisture. Solution is also aided by organic acids developed in the decay of plant material. Chemically, the formation of soluble salts, such as magnesium and calcium sulphates from the reaction of sulphuric acid on magnesium and calcium carbonates, has but little effect, and the mechanical work has

* Twenty-first Annual Report, Department of Geol. and Nat. Hist. Indiana, 1896, p. 320.

been discussed. The oxidation of iron pyrite may result in the formation of sulphuric acid and cause local chemical action of an injurious character.

3. Workability.

Stones suitable for building purposes differ widely in the ease with which they may be quarried and prepared for architectural use. Under workability must be included quarrying, dressing and decorative working. In quarrying, the larger structural features of the rock mass are of great importance. These include bedding, dip or attitude of the strata, and jointing. It is desirable that the beds should be well defined and of such thickness that all the stone may be marketable without an undue amount of labor. Beds too thin for use must be removed at considerable expense of time and labor, while very thick beds make difficult and expensive quarrying on account of the necessity of splitting the blocks into the desired thickness. The horizontal position of bedding greatly facilitates the handling of the quarry product and makes the use of quarrying machinery more possible. Distinct and regular jointing, in at least one direction, is a boon to the quarryman. In many limestone quarries, as for example those at Stone City and LeClaire, Iowa, the rock is so distinctly and perfectly laminated that the split surfaces of much of the quarry product need no further dressing.

In igneous rocks, the absence of true bedding planes makes jointing of even greater importance than in sedimentary rocks, and unless there are rather well-defined joints in an approximately horizontal position, much expensive undercutting or "gadding" is necessary.

Dressing is at best a slow and expensive process, and many otherwise desirable stones cannot be placed on the market because of the difficulty of dressing them. Many stones take the chisel with almost equal facility in all directions, while others have such pronounced bedding or grain, or both, that satisfactory working is very difficult. Fine decorative work on such rocks is almost impossible. Again, certain stones readily take a beautiful and lasting polish, while others are difficultly polished and incapable of retaining a good surface. Easy quarrying, easy working and durability make a desirable combination in building stone.

4. Color.

The tone and permanence of color are of considerable importance in building stones, especially in large cities where fashion rather than utility may be the determining factor in the choice of building material. It is a rare thing to find absolute uniformity of color in a quarry. Very commonly the color changes with depth and remoteness from exposure to atmospheric conditions, and not infrequently the same bed may show marked differences of color on the two sides of the quarry. The common coloring matters of sedimentary rocks are carbonaceous material and salts of iron. Carbonaceous matter usually gives brown and black tones, while the iron salts give blues, grays, buffs, browns and reds—the shade depending largely upon the state of oxidation of the iron present. If the iron is present as a sulphide, weathering is likely to cause oxidation and a darkening of the color toward buff, brown and red. If it is in the protoxide form, the color is likely to be gray, blue-gray and blue. Further oxidation may produce about the same tones of buff, red and brown as those from the iron sulphide. A rock colored brown or red by hematite is likely to keep its color, though in time some of the iron may be washed out and leave the stone of a lighter shade.

The irregular distribution of iron compounds, particularly pyrite, may result in unsightly mottling and streaking of the surface of the wall when oxidation and solution take place.

The color of igneous building stones depends largely upon the important mineral constituents, rather than upon coloring matter proper. For this reason the color is more likely to be permanent. But if the percentage of the ferromagnesian minerals is large, weathering may result in a complete change of tone or intensity of the color, owing to the partial breaking up of these minerals and the separation of iron salts, and a change in their state of oxidation.

COAL ANALYSIS.

By Avery Leavitt, Mechanical Engineering, 1906.

The object of this test has been to determine the comparative values of the various coals of the different Colorado fields, and is only the preliminary to an extensive and complete investigation along the same lines to be followed out at the University of Colorado, as calorimeter tests will be made on all these samples.

The standard method of analysis has been followed with the exception that to get the best results it was found necessary to heat the more volatile coals more slowly than is usual. In the laboratories great care has been taken in testing the various samples, but in only a few cases has it been possible to select the samples personally, and discrepancies are probably due partly to the methods used in sampling.

Samples marked (*) denote personally selected samples, carefully taken by the quartering method directly from the coal bins, and represent the coal as found in market. All others were selected at the mine, in most cases by the superintendent. It will also be noted that in only a few cases were moisture determinations made. This is due to the fact that in most cases the samples had been exposed for some time, and the results would not have been accurate.

The classification of coals, according to Kent, is as follows:

	Carbon Ratio	Fixed Carbon	Vol. H. C.
Anthracite	100 to 12	100. to 92.31	0. to 7.69
Semi-anthracite..	12 to 7	92.31 to 87.5	7.69 to 12.5
Semi-bituminous.	7 to 3	87.5 to 75.	12.5 to 25.
Bituminous	3 to 0	75. to 0	25. to 100.

(No account is taken of impurities or moisture, only fuel constituents being considered.)

This table seems to give higher values than are taken for ordinary market standards, and does not seem to agree with the opinions of other writers; for R. W. Raymond, speaking before the A. I. M. E., refers to Canon City coal—considered by Colorado dealers as one of our best bituminous coals—as a "western lignite."

No.	Name	Moisture	Vol. H. C.	Fixed Carbon	Ash	Sulphur	Locality	Kind
1	*Crested Butte		2.65	89.56	7.79		Crested Butte	Anthracite
2	Anthracite		5.63	89.56	4.81		Anthracite	"
3	*Chandler		37.23	52.85	9.91		Chandler	Non-coking
4	Walsen No. 49		37.85	53.09	9.06		Walsen	Semi-coking
5	Nonac		37.79	56.08	6.22		Canon City	Non-coking
6	Fremont		37.26	54.51	8.23		Williamsburg	" "
7	Rockvale		38.83	57.51	3.65	.49	Rockvale	" "
8	Crested Butte		34.06	62.25	3.69		Crested Butte	Coking
9	Robinson		37.21	54.23	8.56		Robinson	Non-coking
10	Rouse		37.31	57.30	5.39		Rouse	" "
11	*Walsen (Grey Creek)		32.22	55.94	11.84		Walsen	Coking
12	*Rugby (Niggerhead)		37.08	52.56	10.36		Rugby	Non-coking
13	Brookside		38.96	56.18	4.86		Brookside	" "
14	Primero		27.35	66.46	6.19	.70	Primero	Coking
15	Pictou		33.86	55.96	12.18	.855	Pictou	Non-coking
16	Coal Creek		32.55	64.09	3.36	1.16	Coal Creek	" "
17	Rugby		35.45	56.45	8.10		Rugby	" "
18	Hezron		34.61	62.58	2.81		Hezron	" "
19	Cardiff		31.09	57.62	11.29		Cardiff	Coking
20	Hastings	2.66	32.66	53.87	11.11		Hastings	Non-coking
21	*Maitland		26.89	65.62	7.49			
22	Starkville		39.83	55.18	5.01		Starkville	Coking
23	Tabasco		31.94	61.08	6.94		Tabasco	"
24	*Louisville		49.89	46.76	3.35		Louisville	Lignite
25	*Black Diamond		44.09	53.34	2.26		Boulder	"
26	*Mitchell		48.65	48.43	2.92	.295	Mitchell	"
27	Washington	19.02	30.36	46.47	4.15	.52	Boulder	"
28	Colorado Springs		48.84	46.64	4.52	.325	Colo. Springs	"

It will be noticed that Nos. 1 and 2 have been rated as anthracite; Nos. 3 to 23, inclusive, as bituminous; and Nos. 24 to 28, inclusive, as lignite.

Some facts that must be considered in connection with a test of this kind are: first, the difference in values of two grades of the same coal—samples of lump and pea from the same lot often showing a variation of 15 per cent; and, what is of greater importance, the variation in values from the same district. For example, one vein in the southern part of Colorado, in a distance of four miles, shows a change from anthracite to dry non-coking coal. Again, in the Coal Creek District, one-half mile shows a good coking coal and a non-coking variety.

It is hoped to carry on this work on a larger scale, and establish a standard for the new and little-known fields, as well as the older, established ones.

SURVEYING AT THE UNIVERSITY OF COLORADO.

By Howard C. Ford, B. S. (C. E.), 1904, Assistant in Civil Engineering.

The purpose of this paper is to describe the methods of instruction and the work done in surveying at the University of Colorado.

All civil engineering students are required to take three semester hours of surveying during the first semester of the sophomore year, five semester hours of topographic surveying and one of railroad curves, during the second semester, and five semester hours of railroad engineering during the first semester of the junior year. A semester hour is equivalent to one hour of recitation or three hours of field or drafting-room work per week, throughout a semester.

Surveying.—This course consists of recitations, field work and office work. The recitations take up the theory of surveying and the theory and use of the compass, transit, level, plane-table, aneroid barometer, and sextant. Considerable attention is given to United States land survey methods, and to the relocation of corners, lines and boundaries. The text-book used is "Pence and Ketchum's Surveying Manual." Recitations are held no oftener than once a week, the greater portion of the time being devoted to field work.

In the field work, the aim is to give the student familiarity with instruments and methods, by means of numerous problems of varied character, most of which can be done in a single period of three hours. The problems include: pacing; ranging; chaining; measurement of the angles of a triangle with the tape; survey of a field with the tape; passing obstacles and measuring obstructed distances with the tape; determination of magnetic declination; differential, profile and contour leveling; test of the delicacy of a bubble vial; measurement of the angles of a triangle with the transit; prolongation of lines; intersection of lines; traverse of a field; determination of the height of a tower; measurement of the angles of a triangle by repetition; determination of the meridian by Polaris and solar observations, both direct and with attachment; determination of the error of setting a flag-pole with the transit; determination of the stadia constants of a transit; stadia traverse of a field; plane-table surveys of a field by radiation, traversing, and intersection; the three-point problem with the plane-table, Bessel's and the mechanical solution; measurement of the angles of a triangle with the sextant, and the investigation of a land corner.

The office work consists of computations in connection with field problems, plotting and mapping of data obtained in the field, stretching of cross-hairs, comparison of various makes of instruments, sketching of instruments, and other indoor problems. Students are required to execute practice plates in Engineering News lettering throughout the term.

Topographic Surveying.—This course is a continuation of the preceding. Two hours a week are given to recitations and three hours to field and office work. The theory and use of the stadia, base-line apparatus, and other instruments for use in topographic surveying, are studied and the various methods of making topographic and geodetic surveys considered. A complete topographic survey of a portion of the campus, based upon a carefully designed triangulation system, is made. The angles are measured by repetition and the sides chained with precision. Calculations are made and a map drawn. Surveys are made of a city block, a city street, and a mining claim. Topographic drawing is given considerable attention and students are required to execute plates of topographic symbols. The text-books used are "Pence and Ketchum's Surveying Manual" and "Wilson's Topographic Surveying."

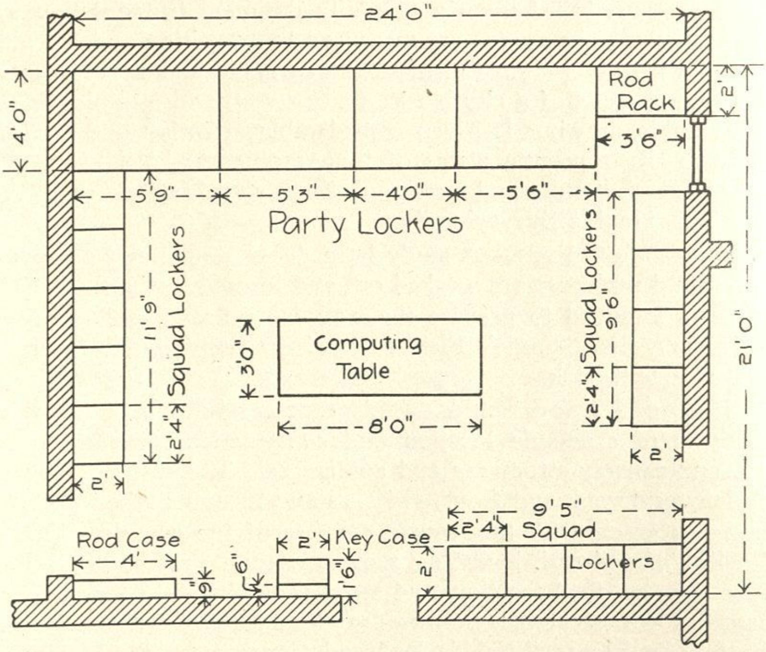
Railroad Curves.—A study is made of simple and compound curves, and problems are worked out and located in the field. This course is intended to prepare the way for railroad engineering in the junior year. "Nagle's Field Manual for Railroad Engineers" is used as a text-book.

Railroad Engineering.—This course takes up in detail the principles of economic location and construction, maintenance of way, and railway structures and appliances. The theory of curves is briefly reviewed, and frogs, switches and turnouts taken up. The surveying going with this course consists of the complete location of a line of railroad, including reconnaissance, preliminary survey, paper location, final location, and cross-sectioning. In the office the quantities are calculated, profiles drawn and a complete map made. The text-books are "Webb's Railroad Construction," "McHenry's Rules and Instructions," "Crandall's Earthwork Tables," and "Talbot's Transition Spiral."

In all courses, field notes are taken in the field, in a standard field book (Keuffel & Esser, 361), with a 4H pencil, using Engineering News style of lettering. Office copies are made of all field notes, on paper ruled in the same manner as the standard field book, and are handed in to the instructor. At intervals, the field books proper are called in for examination.

FIELD ORGANIZATION.—For the purposes of field work, the classes in surveying are divided into squads of two, the same two men working together throughout the entire semester and usually the entire year. For problems which require more than two men, two squads are united to form a party. In Railroad Engineering the parties consist of six to eight men. Squads are designated by the letters of the alphabet, and parties by numbers.

EQUIPMENT.—The equipment consists of seven transits, six levels, three plane-tables, compasses, a sextant, an aneroid barometer, chains, tapes, rods, range poles, hand levels, and other small instruments.



Locker System

Civil Engineering Instrument Room

FIG. 1.

LOCKERS.—The transits, levels and plane-tables are stored in lockers, each locker bearing the same number as the instrument it contains. There are also several lockers for chaining equipment. The arrangement of the lockers is seen in Fig. 1, and the details of construction in Figs. 2 and 3. Of the squad lockers there are thirteen, and in addition four larger party lockers for the use of railroad parties. Miscellaneous small apparatus is stored in one of these large lockers and may be placed in the squad lockers as needed.

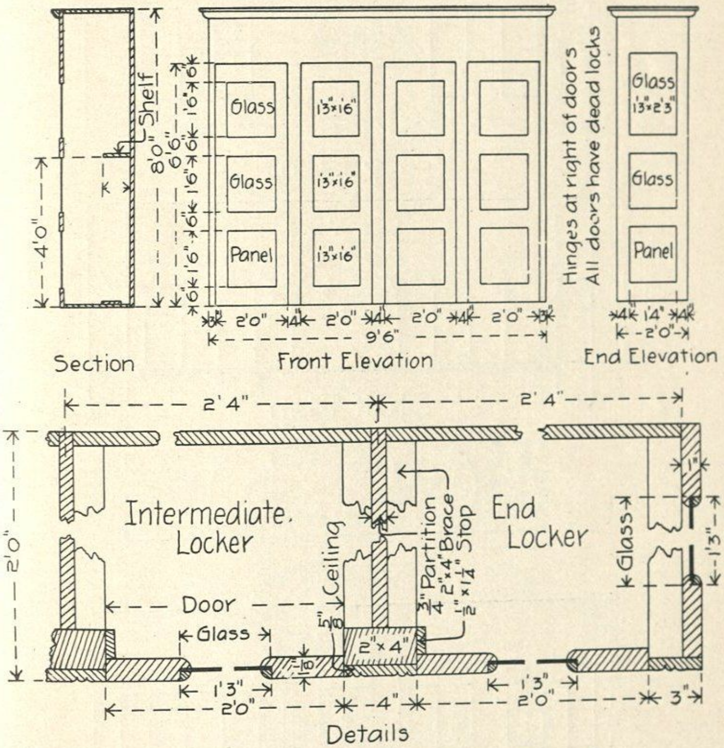


FIG. 2.

There are a rod case and a rack for the storage of leveling rods and range poles, and also a key case. This latter (see Fig. 4) contains twenty-five hooks, on which hang the keys to the various lockers. Between the key and the rod case is a bulletin board for posting assignments of problems and lockers.

The operation of the locker system is as follows: The instructor posts on the bulletin board lists of assignments for several periods

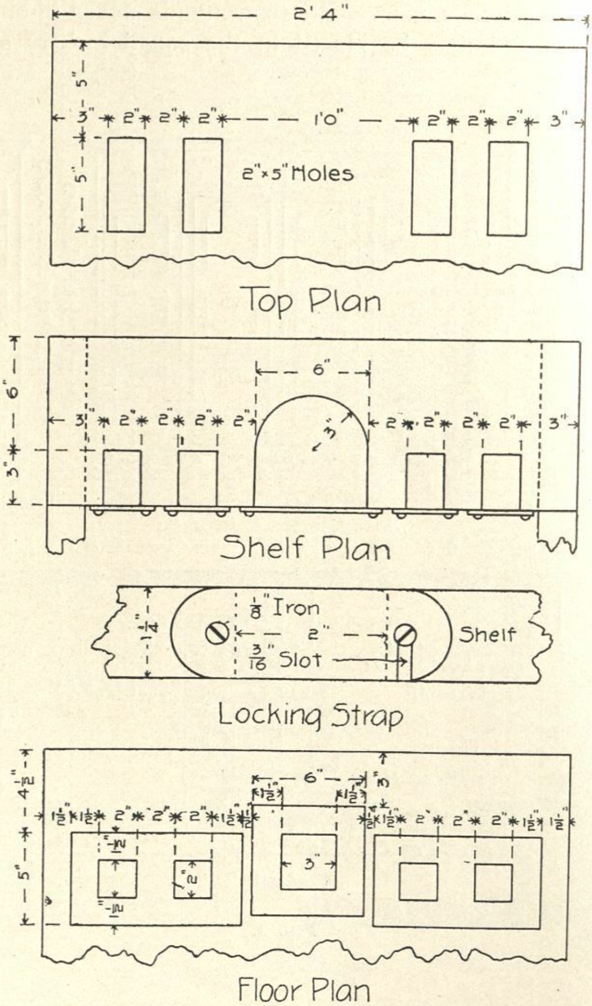


FIG. 3.

ahead, so that the students may know what problems they are to do and may be prepared for the work assigned. A typical assignment is shown on following page.

Date	SQUAD A			SQUAD B			SQUAD C		
	Prob.	Locker	Field	Prob.	Locker	Field	Prob.	Locker	Field
Jan. 12	D10	6	Flag Pole	D7	7	1-5-6-0-3-17	E1	13	
Jan. 15	C14	12		E3	13	12-14-15-4-3-13	D22	6	
Jan. 17	D13	8	1-0-6	C2	10	To C. H. and back	C3	9	Eng. 10′-N. W. Cor.
Jan. 19	E3	13	0-2-8-10-11-13	D13	6	2-7-8	D7	10	1-0-13-12-4-3

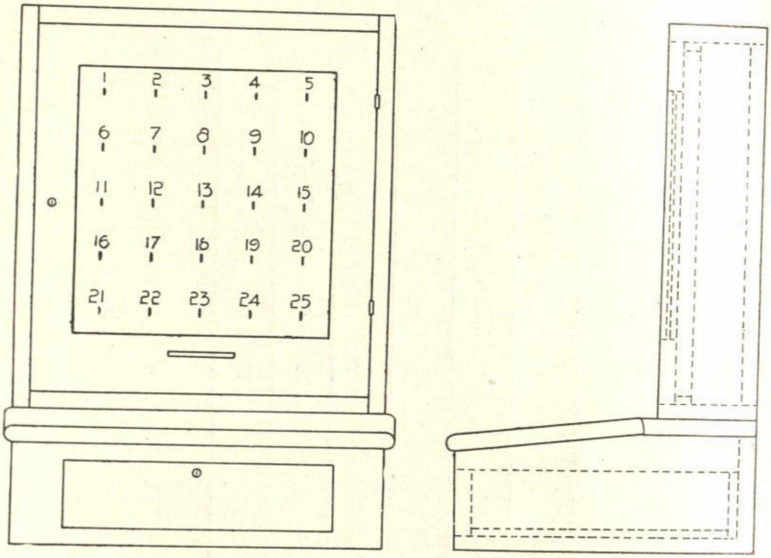


FIG. 4.

SURVEYING INSTRUMENTS

From this a student can see what problem he is to do on a certain day, in what locker his equipment is, and what field he is to survey. He obtains the proper key from the instructor, checks over his equipment, and signs a receipt. This latter is a small manila tag, on one side of which are printed the rules governing the assignment of, and responsibility for instruments, and on the other

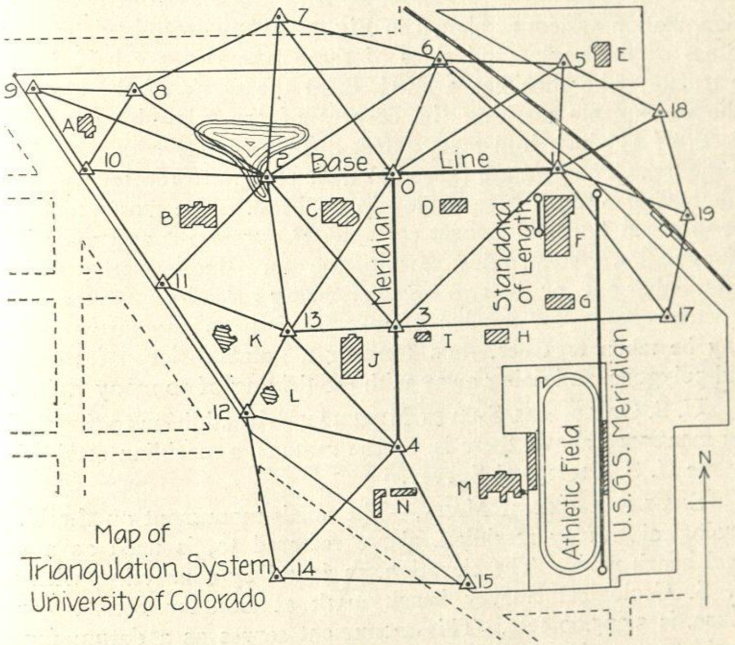


FIG. 5.

side blanks for the date, the locker number, the list of equipment and the signature of the squad leader. The signed tag is hung by the instructor on the hook from which the key was taken, and left there until the end of the term. Thus the instructor may see at a glance what squad had a given instrument on a given day. When the problem is completed, or at the end of the day's work, the equipment is returned to the locker, locked up and the key dropped through the slot in the door of the key case. At his leisure the instructor opens the locker, checks off the equipment and returns the key to its hook. From the time the key is taken from the hook until it is replaced by the instructor, the student by whom the receipt was signed is responsible for the equipment. This system is very effective, saving the instructor a great deal of unnecessary labor, and keeping a perfect record of each instrument, thus fixing the responsibility for breakages or losses.

TRIANGULATION SYSTEM.—The field work is controlled by a triangulation system as shown in Fig. 5. The carefully determined values of the angles and sides of these triangles are held by the instructor, who thus has a check upon the work of the students. The monuments marking the corners of the triangles consist of pieces of 1½-inch iron pipe, 2 feet 8 inches long, with caps fitted to the top. The caps are tapped at their centers to receive a ½-inch bolt having a small hole drilled in its head. The monuments are set in 1:3:6 Portland cement concrete. Courses 1-0 and 0-2 of the triangulation system, being parts of the same line, are used as base lines, either one, or the two together, being available. Course 0-3-4 is a meridian. Any number of courses of the triangulation system may be taken together, thus forming a great variety of triangles and polygons, and doing away with the driving of so many stakes.

U. S. GEOLOGICAL SURVEY MERIDIAN.—In addition to the meridian mentioned above, there is, on the campus, a meridian established by the U. S. Geological Survey.

SEA-LEVEL BENCH MARK.—The north monument on the U. S. Geological Survey meridian, above referred to, is used as a sea-level bench mark. The elevation, as found by connecting with the U. S. Geological Survey bench mark at Boulder county court-house, is 5,395.00 feet. This monument serves as a datum for all level surveys. For practical problems the 5 is omitted, 395.00 being used as datum.

STANDARD OF LENGTH.—This consists of two monuments in front of the engineering building, exactly one hundred feet apart. All tapes are compared with this standard before being used.

THE PRINCIPLES OF WATER-WHEEL DESIGN.

By Norman Read, Electrical Engineering, 1905.

Water wheels of the impulse type are used a great deal, especially in the mountainous regions of the West, for the generation of power.

These wheels, of which the Pelton, Hug, Doble, and Cascade are representatives, are useful only where a considerable head of water is available, as they are designed to operate under heads of from one hundred to three thousand feet. These wheels are very efficient converters of power, having efficiencies which run from seventy-five to ninety per cent.

The general construction of these wheels, familiar to all engineers, is as follows: They consist of a spoke or disc wheel on a horizontal shaft, and attached to the periphery of this wheel a number of buckets against which the stream of water impinges.

The nozzle from which this stream issues, has either a number of interchangeable tips, or a needle-regulating device to vary the size of the stream.

The theoretical horse-power generated by a stream of water is expressed by the equation:

$$H.\,P. = \frac{H \times Q \times 62.5}{33000};$$

where H = effective head in feet,

Q = quantity of water passing through the nozzle per minute.

The value, Q, depends entirely upon the supply, and design of the pipe line and nozzle.

The effective horse-power is found by multiplying the theoretical by the efficiency of the wheel. This efficiency is dependent practically on two losses, namely: windage and friction, and losses in the bucket itself.

The windage and friction loss is brought to a minimum by good mechanical design, so that it is to the design of the buckets that manufacturers and inventors must turn their attention to increase water-wheel efficiency.

The Bucket.

In the design of these buckets there are certain fundamental principles which all designers must take into account: (1) That the stream of water must strike the bucket and be reversed without shock; (2) That the path of the stream shall be a smooth curve and have as little resistance or skin friction as possible; (3) That the bucket shall free itself from water and that there shall be no cushioned water, and (4) That the water thrown out of the bucket shall not strike the back of the next succeeding bucket.

The first condition is met by determining by graphical methods the proper shape of bucket. The rim velocity for maximum efficiency theoretically should be .50 × velocity of the stream, but the best results have been obtained on the various types by assuming the rim velocity equal to .44 — .48 × stream velocity. Having these velocities it is a simple matter, by combining, to lay out a smooth curve that will take and discharge the water without shock.

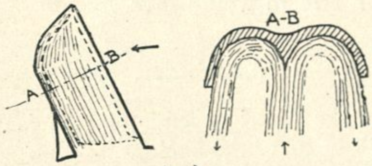
The second condition makes it imperative that the water shall be kept in as solid a stream as possible. The Pelton Co., in their bucket, use a dividing wedge (a) and discharge the water at both sides. This spreads out the water and the skin friction is increased. In the Hug bucket, the stream strikes a flat lip and is only divided after entering the bucket and the water is discharged from the two ears—a-a(b)—in solid streams. In this way the skin friction is reduced to a minimum, while the internal friction is only slightly increased.

In complying with the third condition, the designer must allow plenty of space for the water to travel along its path and yet he must be careful not to spread the water and thus increase the skin friction.

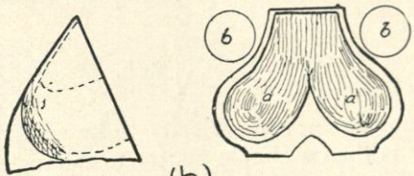
Many designers have attempted to stop the water in the bucket by ridges in order to get the full force of impulse, but they have lost sight of the fact that water cannot be treated as a solid and that cushioning will invariably follow.

The fourth condition has been met in various ways. Some have decreased the angle of discharge in order to throw the water outside the next bucket as shown in (a), the Pelton form, while in the Hug, the bucket is of such a form that the returning stream cannot possibly touch the next bucket—(b)b-b.

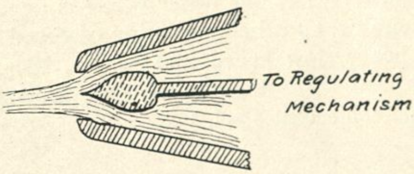
This condition, if not complied with, would produce a very noticeable effect, especially when the water wheel was overloaded. In this case, with the slowing down of the wheel, would come an increase in the amount of water in each bucket, and the returning water would hit the back of the next bucket, thus retarding the wheel, reducing the efficiency. Of course the above are only the fundamental principles of this design, and simple as it may seem,



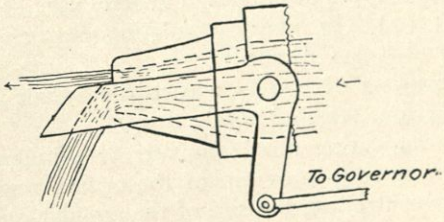
(a)



(b)



(c)



(d)

it must not be concluded that these are the only problems to be dealt with. The field of water-wheel design covers an area as vast as that of the design of the steam engine, or any other prime mover.

Buckets built in exact proportion to the stream diameter will not do, since the amount of water handled by the bucket does not increase in proportion to the stream diameter, but to the square of the diameter. Thus, in wheels for a two-inch stream, the buckets must be made large enough to handle four times the amount of water that a one-inch stream would give.

The Wheel.

The diameter of the wheel depends on two factors: The wheel must be large enough to carry the buckets, and also must be of such a size as to give the required number of revolutions per minute. Having calculated the velocity of the stream through the nozzle by the formula

$$V = \sqrt{2gh},$$

and having assumed the rim velocity to be a certain percentage of this velocity, it is then a simple matter to calculate the diameter for any given number of revolutions per minute.

In modern power work the water wheel is generally direct connected to its generator, and the calculation of speed is rather important. For low heads, low speed and power, the wheels are constructed of cast iron. For high heads they are made of steel and bronze, or of malleable cast steel.

The Nozzle.

There are three types of nozzles in general use: (1) The straight nozzle and tip; (2) The needle-regulating nozzle, and (3) The deflecting ball-and-socket nozzle.

The first consists of merely a cast-iron nozzle-piece threaded to receive the various sizes of nozzle tips.

The needle-regulating nozzle consists of a hollow nozzle with a spindle which, moving in or out of the orifice, regulates the size of the stream by controlling the size of the annular opening between the spindle and the nozzle (c).

The deflecting nozzle consists of a straight cast-iron nozzle-piece, having nozzle tips fitted with a ball-and-socket joint, so that the governor may deflect the water away from the wheel. A regulating device used a great deal with the common nozzle consists of a hood that is so hinged that it may be drawn up by the governor and part of the stream of water deflected (d).

For exact speed-regulation the deflecting nozzle or hood is generally used, while the needle-nozzle is used to vary the size of stream from time to time for greater economy in the use of water.

In electric installations, the wheels and nozzle are all incorporated in a heavy cast-iron case, and the whole presents a very strong and neat appearance, and while in operation the wheels are almost noiseless.

For cheapness, cleanliness and noiselessness the water wheel stands without a peer; and the future for such installations, especially in mountainous regions, is unlimited; and at the present time it is estimated that in our small mountain streams there are millions of horse-power going to waste which could well be used to furnish light and power to the cities on the plains.

SPECIFICATIONS FOR LEVELS AND TRANSITS.

By Howard E. Phelps and Edwin R. Weeks,
Civil Engineering, 1907.

The instrumental equipment of the University of Colorado for the use of students in surveying includes seven transits and five levels, representing various makers: W. & L. E. Gurley, C. L. Berger & Sons, Keuffel & Esser, T. Cooke & Sons, and Heller & Brightly.

Upon a thorough examination of these instruments, the results of which are given in the accompanying table, were based the following specifications, which are intended to serve as a guide to engineers in selecting instruments for general service.

Specifications for an Engineer's Level.

The telescope shall have a length of from eighteen to twenty inches, shall be inverting and shall have a magnifying power of from twenty-five to thirty-five diameters.

The objective shall have a clear aperture of about one and one-fourth inches, and shall give good illumination and a clear, sharp image.

The cross-wires shall be made of spider lines.

The bubble shall be about eight inches in length and shall have a radius of curvature of from one hundred and fifty to two hundred feet.

The instrument shall be provided with four leveling screws.

The level, complete, with tripod, shall weigh about twenty pounds.

In addition to the above may be mentioned a few points which are convenient, although not necessary:

Stadia wires are useful in some cases.

A split-leg tripod is to be preferred.

A cloth finish on telescope and bubble-case is very satisfactory as resisting the effects of the weather.

Specifications for an Engineer's Transit.

The telescope shall be approximately eleven inches in length, shall be inverting, and shall have a magnifying power of about twenty diameters.

The objective shall be as nearly as may be one and one-fourth inches in diameter, having a clear aperture of one and one-sixteenth inches. The illumination shall be good, and the image clear and sharply defined.

The cross-wires shall be made of spider lines, and shall comprise the usual cross-wires and also stadia wires, both of which shall be adjustable.

The horizontal circle shall be from six and one-half to eight inches in diameter and shall be graduated to half degrees, reading by two opposite verniers to single minutes of arc. The verniers shall be placed at an angle of thirty degrees to the line of sight.

The vertical circle shall be approximately five inches in diameter, shall be graduated to half minutes, and shall read to single minutes by means of a vernier, which latter shall admit of adjustment of its zero point. The whole vertical circle, exclusive of a space opposite the vernier, shall be protected by a metal casing.

The attached bubble shall be not less than four and preferably five inches in length and shall have a radius of curvature of not less than one hundred feet.

The instrument shall be provided with a shifting head and four leveling screws.

The transit shall be mounted on a split, adjustable-leg tripod, and shall weigh, complete, not to exceed twenty-eight pounds.

As in the case of the level, a cloth finish on telescope, attached bubble and standards, is very satisfactory.

COMPARISON OF TRANSITS AND LEVELS

TRANSITS

TRANSITS	TELESCOPE				PLATES			Leveling Screws	Weights, Lbs.	REMARKS
	Length	Power	Dia. Object	Aperture	Inner Dia.	Outer Dia.	Reading			
Gurley 1........	11¼ in.	35 Dias.	1¼ in.	1 1/16 in.	6¾ in.	8 in.	1 min.	4	28¾	Definition and Illumination, good
Gurley 2........	11 "	19 "	1⅜ "	1 "	6½ "	8 "	1 "	4	28¾	" " " fair
K. & E.........	10½ "	12 "	1¼ "	⅞ "	6½ "	8 "	20 secs.	3	27½	" " " good
K. & E. L. M. ..	7½ "	15 "	1⅛ "	⅝ "	5½ "	6½ "	1 min.	3	20½	Illumination, excellent; Definition, sharp
Berger..	11¼ "	20 "	1¼ "	1 1/16 "	6¼ "	7½ "	1 "	4	26¼	Excellent Telescope, Inverting
Cooke..........	9 "	22 "	1¼ "	1⅛ "	5 "	5 "	20 secs.	3	21¾	Plates read vertically, Inverting
H. & B.....	11½ "	28 "	1⅜ "	1 "	6½ "	7½ "	1 min.	4	28	Very poor Illumination and Definition

LEVELS

LEVELS	TELESCOPE				BUBBLE		Leveling Screws	Weight, Lbs.	REMARKS
	Length	Power	Dia. Object	Aperture	Length	Rad. Cur.			
Gurley 1........	19 in.	44 Dias.	1¼ in.	1 3/16 in.	7½ in.	170 ft.	4	21¾	Definition, good; Illumination, sharp
Gurley 2	20 "	48 "	1⅜ "	1 1/16 "	7½ "	250 "	4	21¼	" " " "
Gurley 3........	20 "	....	1⅜ "	1¼ "	7⅞ "	....	4	22¾	
Berger.......	18 "	35 "	1⅜ "	1¼ "	8 "	147 "	3	21¼	Definition, excellent; Illumination, excellent
K. & E..........	15 "	23 "	1¼ "	1 "	6½ "	46 "	3	18¾	" " " good