economy; the system itself, and general operation being substantially perfected. The repairs on the work constructed two years ago, after we had finished experimenting on the original trial lines, have been only nominal, and the loss by leakage small, and this due to the carelessness of employés. By the improved fittings, leakage has been made almost impossible.

We operated, at first, with machines of twenty to thirty tons daily capacity; and continued to do so until more than two years ago, when a ninety-ton machine was added in St. Louis. This has been working successfully ever since, and a duplicate has since been used in connection with it. Another of the same size was put in operation eighteen months ago in Denver, and is working satisfactorily. The old machines are being utilized in the business of ice making; and at the same time are in readiness to take care of the street-line work in case the new machines should by any chance get out of order; in which event, the ice-dealers only would have to fall back on their store of natural ice.

THE USE OF STEEL IN ELECTRIC MACHINES.

BY H. F. PARSHALL.

During the last few years steel has come to be used largely in the magnetic parts of electrical machines. In the magnet frames of some classes of machines the changes brought about have been most marked. In armature cores which require thin plates there has been no change, since the requirements are so rigid that the properties, either physical, or chemical, of steel, differ but little from wrought iron; in fact, the distinction between steel and iron in this case is made on account of the difference in the processes of steel and iron making.

By the use of steel in magnet frames street-car motors have been so completely changed that the motors of to-day, so far as form and appearance go, are hardly comparable with those of a few years ago. Before it was possible to

get steel castings of complex form, street-car motors were limited to such forms of construction as could be built up with elementary blocks of forged iron.

How great the change has been is evident upon examination of *Figs. 1, 2, 3 and 4*. *Figs. 1 and 2* show two early

FIG. 1.

FIG. 2.

types of street-car motors that have been widely used, that were constructed from the forms of iron obtainable when the machines were designed. *Figs. 3 and 4* show the outlines of a modern street-car motor constructed of steel castings. It will be noticed that a water-proof casing has

been cast with the magnetic circuit, that the motor is much more compact, and that the parts liable to mechanical injury are thoroughly protected. The forms of motor practicable to build from forgings do not lend themselves well to single reduction, while with the steel castings now obtainable,

FIG. 3.

FIG. 4.

single reduction motors are easily constructed and economical of material.

Further, owing to the range of form permissible, it is possible to arrange the parts so that the length of the magnetic circuit is shortened, thereby diminishing the weight

of the motor about twenty per cent. to the advantage of repairs on track and trucks.

In stationary motors corresponding changes have been made, or are now contemplated. In the case, however, of generators the advantages obtainable from the use of steel are less marked, both from the standpoint of form and of economy, the principal reasons being that this class of machinery is not restricted as the above classes as to size, form, or weight.

The ratios of permeability and cost per pound of steel and cast iron, as used in best practice, show a margin of

FIG. 5.

about twenty per cent. in favor of the use of steel. The ratios of the permeability to the cost of steel and wrought iron forgings of simple form show a margin of twenty per cent. to twenty-five per cent. in favor of the use of wrought iron.

Reasoning from the above and neglecting any difference in machining, it would appear that magnet frames constructed entirely of steel would be cheaper than those constructed of cast iron. Further, the difference is considerably increased on account of the greater amount of copper required in the magnetizing coils of a cast-iron machine, this increase being due to the greater length of turn of the magnetizing coils on account of the greater section of the

cast iron required to support a given magnetic flux. In the conditions obtaining at the present time steel magnet frames and magnetizing coils cost only about seventy-five per cent. of magnetically equivalent cast-iron magnet frames and magnetizing coils.

It would further appear from the ratios given above, of the permeability and cost of steel and forgings, that a magnet frame constructed of forgings would be the cheapest of all.

By referring, however, to *Fig. 5*, which shows a typical

FIG. 6.

magnet frame, it will be seen that it is not practicable now to construct dynamo frames entirely of forgings. It is practicable, however, to construct magnet frames with the yoke of cast iron, the magnet cores of forgings and the polar projections of cast steel, as is shown in *Fig. 6* on the same scale as *Fig. 5*. Such a structure costs about the same as one entirely of cast steel, and possesses the advantage that both cast iron and forgings are more uniform in magnetic qualities, easier to machine, require less chipping and are more easily finished. There is, however, the disadvantage

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that the weight of cast iron as used in practice is about two and one-half times that of steel for same magnetic results, and thus the parts that can be made of cast iron are in many cases very massive and difficult to move.

As a practical example, we will take the 1,500 kilowatt generator, recently designed for the General Electric Company, and now in operation in the Brooklyn Railway Station. The magnet yoke is constructed of steel and weighs 38,000 pounds. If it were constructed of cast iron it would weigh

FIG. 7.

87,000 pounds, such a weight requiring extraordinary facilities both as to shipping and handling in the shop.

We will now consider the quality of steel required for magnet frames, meaning by steel such combinations of iron as can be cast and are free from uncombined carbon or graphite. The effect of combined carbon or graphite is to lessen the magnetic continuity and greatly lessen the permeability.

Figs. 7 and 8 have been included to illustrate the mag-

netic effect of the presence of graphite even though, by the above definition, graphitic irons are not directly in the line of the present discussion.

It is the practice of the General Electric Company to make a chemical analysis of a sample of the steel in each casting before it is used in construction. This was occasioned by the considerable variation found in steel made, apparently, under the same conditions. In one notable case the amount of copper in the magnet coils of a large genera-

FIG. 8.

tor had to be increased thirty per cent., owing to the presence of innumerable blow-holes throughout the yoke and pole pieces. An examination of a great number of these analyses does not indicate clearly the relation between the chemical and magnetic properties. The particular value of such analysis seems to be from the clue furnished to the physical properties, *i. e.*, as to the probable softness and homogeneity of the steel.

It may, however, be roughly stated that good cast steel

should not have greater percentages of impurities than are given in the following analysis :

Carbon,	·25
Manganese,	·60
Silicon,	·20
Phosphorus,	·08
Sulphur,	·05

In practice, carbon is the most objectionable impurity, and can to advantage be restricted to smaller amounts than above quoted. The results of a great number of tests and

FIG. 9.

analyses were plotted, and it appeared quite evident that the falling off of permeability was proportional to the amount of carbon contained and by diminishing the amount of carbon, other conditions remaining the same, there was a corresponding increase of permeability.

Manganese below ·6 per cent. seems to have but little effect. The presence of manganese in large quantities deprives the steel of nearly all magnetic susceptibility, a twelve per cent. mixture having scarcely greater magnetic susceptibility than air.

Silicon at the magnetic densities used in practice is less objectionable than carbon, but at high densities it appears to diminish the magnetic qualities of iron to some extent. Its presence is objectionable in that it facilitates the formation of blow-holes, and like manganese, has a hardening effect, rendering the steel hard to tool.

Phosphorus and sulphur, limited to the amounts stated above, are not objectionable.

In *Fig. 9* the upper curve shows what in ordinary practice

FIG. 10.

is termed good steel, the lower curve shows what is termed poor steel. Corresponding analyses are shown in Tables I and II.

TABLE I.—DATA OF TEN FIRST QUALITY SAMPLES OF CAST STEEL.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	Average.
B for H = 15, 12,200	12,000	12,100	12,900	13,000	12,300	13,100	12,100	12,600	13,000	12,500	
B for H = 25, 14,100	13,600	13,900	14,400	14,600	13,900	14,500	13,700	14,200	14,500	14,100	
B for H = 50, 15,800	15,300	15,600	15,900	16,600	15,600	16,100	15,400	15,800	16,000	15,800	
B for H = 75, 16,600	16,200	16,600	16,500	17,600	16,400	17,100	16,300	16,700	16,600	16,700	
Carbon, . . .	'240	'267	'294	'180	'290	'250	'200	'230	'170	'180	'230
Phosphorus, .	'071	'052	'074	'047	'037	'093	'047	'100	'089	'047	'057
Silicon, . . .	'200	'236	'202	'120	'036	'230	'170	'160	'150	'120	'195
Manganese, .	'480	'707	'655	'323	'550	'410	'530	'450	'390	'323	'482
Sulphur, . .	'040	'060	'050	'050	'050	'030	'030	'040	'020	'030	'042

TABLE II.—DATA OF TEN SECOND QUALITY SAMPLES OF CAST STEEL.

	<i>I.</i>	<i>II.</i>	<i>III.</i>	<i>IV.</i>	<i>V.</i>	<i>VI.</i>	<i>VII.</i>	<i>VIII.</i>	<i>IX.</i>	<i>X.</i>	<i>Average.</i>
B for H = 15, 10,600	10,600	10,700	9,000	9,300	10,000	10,400	10,000	9,300	11,300	10,120	
B for H = 25, 12,700	12,700	13,100	11,200	11,600	12,100	12,500	12,400	11,800	13,500	12,360	
B for H = 50, 14,900	14,600	15,100	13,500	13,900	14,300	14,400	14,700	14,100	15,700	14,520	
B for H = 75, 15,900	15,600	15,900	14 400	14,900	15,300	15,300	15,700	15,000	16,500	15,450	
Carbon, . . .	'250	'280	'195	'333	'337	'366	'409	'318	'702	'380	'357
Phosphorus, . .	'087	'076	'028	'059	'045	'151	'063	'107	'084	'066	'077
Silicon, . . .	'210	'210	'683	'292	'302	'476	'444	'203	'409	'550	'378
Manganese, . .	'790	'720	'815	'681	'642	'617	'640	'1'636	'088	'790	'742
Sulphur, . . .	'020	'030	'040	'060	'070	'040	'010	'030	'050	'030	'038

Fig. 10 shows curves and analysis of two different samples of steel showing the effects of combined carbon.

In *Fig. 11* is given similar curves for mitis iron and in Table III corresponding analyses. An inspection of these analyses show they do not furnish a clear indication as to the effect of the various impurities. It will be noticed, however, that in a poor quality there is generally an excess of impurities, this excess of impurities denoting a lack of homogeneity and a greater degree of hardness than in a good steel.

TABLE III.—DATA OF TWELVE SAMPLES OF MITIS.

	<i>I.</i>	<i>II.</i>	<i>III.</i>	<i>IV.</i>	<i>V.</i>	<i>VI.</i>	<i>VII.</i>	<i>VIII.</i>	<i>IX.</i>	<i>X.</i>	<i>XI.</i>	<i>XII.</i>	<i>Average.</i>
B for H = 15,	12,600	14,500	14,500	12,700	13,900	14,200	14,000	10,800	10,000	12,900	12,700	11,800	12,900
B for H = 25,	13,600	15,600	15,700	14,500	15,000	15,700	15,300	12,650	11,900	14,300	14,300	13,400	14,300
B for H = 50,	14,800	16,900	16,700	16,200	16,300	16,800	16,500	14,300	13,900	15,900	16,000	15,000	15,800
B for H = 75,	15,500	17,600	17,500	16,900	17,000	17,400	17,100	15,200	14,800	16,800	16,800	15,700	16,500
Carbon, . . .	'065	'105	'106	'125	'136	'212	'214	'216	'235	'241	'242	'260	'180
Phosphorus, . .	'083	'093	'112	'166	'053	'056	'052	'128	'065	'093	'094	'120	'093
Silicon, . . .	'073	'045	'050	'046	'111	'126	'111	'083	'122	'072	'099	'020	'080
Manganese, . .	'112	'108	'099	'120	'191	'405	'401	'167	'107	'248	'253	'140	'196
Sulphur, . . .	'150	'050	'050	'050	'030	'040	'040	'010	'030	'030	'030	'030	'045
Aluminum, . .	'079	not determined,	'059	'183	'008	'273	not determined,	'152	'055	'120	'119	'080	'113

The effect of annealing on the permeability of cast steel varies considerably, according to the treatment at the foundry. In an ordinary sample annealing seems to increase the permeability for low magnetizations, but for high magnetizations the effect is less marked.

The effect of tempering is to greatly diminish the permeability.

Results of an interesting experiment illustrating the intimate connection between the physical and magnetic properties of steel are shown in *Fig. 12*. Curve 1 shows a

test of sheet steel as received. Curve 2 shows test of same after annealing. Curve 3 shows test of the same sample after being subjected to a pressure of 40,000 pounds per square inch. It will be noticed that the annealing in this case materially increased the permeability, but that the sub-

FIG. 11.

jecting of the sample to pressure diminished the permeability below its original value. The analysis of this test is:

$$C = .049$$

$$P = .117$$

$$Mn = .369$$

$$Si = .202$$

$$S = .1$$

We will next consider the quality of steel that is most suitable for plates of armature cores. These plates in ordinary practice vary from .014 inch to .030 inch in thickness; in consequence, steel has to be of very good quality, mechanically, otherwise it would not withstand the rolling process. There is very little difference between the chemical

analysis of the steel that is ordinarily used in these plates and wrought iron. In general, plates made by the steel process show more manganese, and those made by the iron process show more silicon; in fact, these are the clues that serve in practice to identify the processes. Steel to be of the most satisfactory quality must have a minimum tendency to persist in any magnetic state it may have acquired. This may be expressed in other words, by saying that the energy required to overcome the intermolecular

FIG. 12.

friction brought about by changing the direction of magnetization of the iron should be a minimum. This tendency to persist in a formerly acquired magnetic state is termed hysteresis, and the amount of hysteresis is measured by the amount of energy required to completely reverse the direction of magnetization.

In *Fig. 13* are given a number of curves for different cycles, showing how hysteresis varies with the intensity of magnetization in ordinary quality sheet steel.

It is most difficult to determine the effect of the chemical constituents upon the hysteretic loss in sheet iron and steel. This is owing to the fact that with the usual compositions low in silicon, a very slight difference in the annealing will make a disproportionately great difference in the hysteretic loss, and as it is a matter of great difficulty to subject different samples to even approximately similar conditions of annealing, it is hard to illuminate this large

FIG. 13.

variable effect sufficiently accurately to determine at all satisfactorily the residual effects of the chemical constituents.

Silicon in the proportions occurring in sheet iron and steel is not very harmful except that it tends to prevent to a certain extent the improvement that would otherwise result from annealing.

Manganese and sulphur up to a considerable amount (·6 per cent. for manganese, and ·06 per cent. for sulphur) do not increase the hysteretic loss.

From the tests made up to the present time the following conclusions seem warranted. Phosphorus is especially objectionable as regards the hysteretic loss and has more tendency to increase the hysteretic loss than carbon.

Two tables are given below, showing the amount of energy dissipated per cycle, first in six exceptionally good samples, and second in six exceptionally poor samples.

TABLE IV.

	<i>I.</i> <i>per cent.</i>	<i>II.</i>	<i>III.</i>	<i>IV.</i>	<i>V.</i>	<i>VI.</i>	<i>Average.</i>
Carbon,	'076	'085	'072	'086	'095	'078	'082
Phosphorus,	'058	'052	'057	'084	'075	'056	'064
Silicon,	trace	'005	'006	trace	'007	'012	'005
Manganese,	'297	'021	'417	'320	'322	'026	'246
Sulphur,	'060	'030	'030	'040	'030	'010	'033
Ergs per cubic centimeter per cycle at a density of 8,000 lines per square centimeter,	2,800	3,100	2,800	3,000	3,300	3,400	3,070
Material,	sheet iron.		SS	SS	SS	SS	

TABLE V.

	<i>I.</i>	<i>II.</i>	<i>III.</i>	<i>IV.</i>	<i>V.</i>	<i>VI.</i>	<i>Average.</i>
Carbon,	'153	'063	'117	'099	'090	'153	'113
Phosphorus,	'032	'075	'101	'135	'101	'081	'088
Silicon,	'007	'003	'005	'000	'027	'002	'008
Manganese,	'430	'036	'401	'449	'449	'486	'375
Sulphur,	'050	'030	'010	'030	'030	'070	'045
Ergs per cubic centimeter per cycle at a density of 8,000 lines per square centimeter,	8,300	9,000	8,500	8,050	8,000	8,000	8,310
Material,			SI	SI	SS	SS	

The average of Table V shows somewhat larger percentages of all impurities than that of Table IV. But the exceptionally poor results of Table V, as well as the exceptionally good results of Table IV are undoubtedly due largely to the difference in the annealing. Annealing has a tendency to make the structure of the iron more homogeneous, leaving the molecules freer to change their direction. Experiments have been made to show that hysteresis can be lessened from 8,000 ergs per cubic centimeter per cycle to about 2,000 by careful and continuous annealing.

With respect to the use of steel in general for magnetic purposes, it may be stated that the most valuable products are those that are found to be softest and most homogene-

ous. In a given sample any physical change which increases the permeability and correspondingly diminishes the hysteresis. In different samples steel of the highest permeability may not give the best results as to hysteresis; thus a trace of uncombined carbon has a tendency to greatly lessen the permeability, but does not seem to greatly affect the hysteresis.

The most hoped-for improvements in steel are in the making of castings free from blow-holes and surface defects, requiring a minimum of finish, and which are soft and easily machined. Such castings would certainly prove satisfactory from a magnetic standpoint.

In conclusion I wish to express my indebtedness to Mr. H. M. Hobart for the assistance he has rendered in the collection of the data used in this paper.

A PLEA FOR THE STUDY OF ELEMENTARY FORESTRY IN THE LOWER SCHOOLS.

BY EDWIN J. HOUSTON, PH.D.

[*A lecture delivered before the Franklin Institute, November 3, 1893.*]

[*Concluded from p. 31.*]

A wide dissemination both of the knowledge of the evils following the removal of the forests, as well as the benefits ensured by their protection is necessary for the public welfare. How shall this much-needed information be given to the general public? How best may these important facts be made matters of common knowledge? I would answer not only by means of suitable literature in books, newspapers, and periodicals generally; not only by means of lectures and addresses, but also, indeed, I believe mainly, by means of proper instruction given to the children of our lower schools.

I would, therefore, urge that elementary forestry be made a study in our lower schools for the following reasons; viz.,

(1) As a matter of public policy, because I believe such study necessary properly to instruct the public through the