REPORT

ON THE

MANUFACTURE OF ENGINES AND BOILERS,

WITH

A REVIEW OF THE PRINCIPAL TYPES

OF

ENGINES FOR MANUFACTURING PURPOSES,

BY

CHARLES H. FITCH, D. E.,
SPECIAL AGENT.

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LETTER OF TRANSMITTAL.

New Haven, Connecticut, *October* 1, 1881.

Prof. William P. Trowbridge,
Chief Special Agent:

Sir: The report herewith submitted presents an outline of a very large subject. It deals rather more fully with the economy of manufacture than with the types and uses of engines and boilers. The statistics of the use of power are prepared and reported upon by others, and this fact precludes their consideration here.

The merits of the different types of engines are well understood, but they have not here been very closely compared, for although reports of trials and tests in great numbers are available, their results are not considered finally decisive of the merits of peculiar features. In close competition in economy trials the differences shown are often due to proportions and running condition no less than to unique design, and despite the high results obtained in trials, there is great room for improvement in the economy of ordinary practice even in those sections of the country in which it is of the highest financial consequence.

Economy of manufacture is a consideration of high importance and deserving comprehensive study.

Every slight improvement in machinery, or in system, requires greater intelligence in management, and produces better results, registering a sustained advance both in intellectual power and in material wealth.

Respectfully,

CHARLES H. FITCH,
Special Agent.

STATISTICS OF THE MANUFACTURE.

The manufacture of steam engines and boilers in the United States.

States and territories.	Number of establishments.	Capital.	Greatest number of hands employed at any one time during the year.	Average number of hands employed.			Wages and hours of labor.					Materials.	Products.
				Males above 16 years.	Females above 15 years.	Children and youth.	No. of hours in the ordinary day of labor.		Average day's wages for a skilled mechanic.	Average day's wages for an ordinary laborer.	Total amount paid in wages during the year.		
							May to November.	November to May.					
The United States ..	462	$24,739,836	29,843	23,504	4	628	10	10	$2 35	$1 25	$11,469,240	$20,021,240	$38,221,036
Alabama	3	24,000	57	49	....	5	10	10	3 00	1 00	18,100	14,000	38,000
California	26	915,450	1,167	883	....	15	10	9	3 30	1 05	522,590	856,822	1,035,808
Colorado	1	15,000	24	21	....	3	10	9	3 00	2 50	15,600	60,600	100,000
Connecticut	12	281,625	478	372	....	8	10	10	2 45	1 40	180,413	387,667	665,671
Delaware	4	1,465,000	1,407	1,279	....	10	10	10	2 50	1 00	608,512	1,868,876	2,848,825
Georgia	1	112,344	110	113	....	6	10	10	2 50	75	34,822	27,332	82,179
Illinois	20	667,700	1,219	940	....	44	10	10	2 50	1 35	472,700	1,092,800	1,808,378
Indiana	17	1,110,500	1,518	1,437	....	27	10	9	2 15	1 30	605,115	2,122,700	3,051,825
Iowa	7	75,500	137	94	....	2	10	10	2 45	1 40	49,700	69,668	175,712
Kansas	3	90,200	95	79	....	....	10	9	2 60	1 35	49,400	36,868	114,000
Kentucky	14	362,000	428	340	....	9	10	10	2 40	1 25	158,450	245,673	510,991
Louisiana	7	22,250	91	42	....	5	10	10	3 30	1 45	20,050	26,500	64,000
Maine	2	30,000	45	20	....	....	10	10	2 10	1 85	13,800	18,500	30,000
Maryland	10	602,000	919	707	....	11	10	9	2 15	1 20	300,000	433,925	957,775
Massachusetts	18	1,271,000	1,061	995	....	9	10	10	2 50	1 45	404,845	1,108,316	1,919,951
Michigan	21	1,203,550	1,225	892	....	51	10	10	2 15	1 25	409,504	660,442	1,464,234
Minnesota	4	24,450	107	86	....	....	10	10	2 60	1 55	52,800	87,000	170,000
Mississippi	2	6,500	24	24	....	....	10	10	4 50	2 35	19,335	11,000	38,000
Missouri	13	458,250	858	780	....	....	10	9	2 50	1 40	358,014	504,887	1,034,667
New Hampshire	2	220,000	228	161	....	43	10	10	2 00	1 20	86,335	145,486	266,400
New Jersey	21	415,300	694	587	....	6	10	10	2 15	1 00	289,331	385,057	812,910
New York	69	4,660,975	6,594	4,431	3	133	10	10	2 25	1 30	2,393,716	2,481,349	6,022,973
North Carolina	1	2,000	12	7	....	....	11	10	2 25	1 00	3,500	700	6,000
Ohio	43	2,623,950	2,614	2,250	....	37	10	9	2 25	1 25	938,357	1,642,142	3,373,091
Oregon	7	156,500	202	116	....	6	10	10	2 50	2 00	102,484	81,307	237,200
Pennsylvania	89	5,665,792	5,504	4,512	....	128	10	10	2 20	1 20	2,030,595	4,056,718	7,308,283
Rhode Island	5	795,000	777	653	....	2	10	10	2 30	1 30	356,588	378,110	932,252
South Carolina	1	30,000	40	35	....	3	10	10	2 50	50	10,000	10,000	40,000
Tennessee	8	90,100	231	166	....	6	10	10	2 50	1 05	65,376	97,574	250,525
Texas	2	7,500	24	12	....	4	10	10	3 10	1 65	8,500	10,000	27,000
Utah	1	15,000	6	1	....	1	10	10	3 50	1 00	780	2,100	3,840
Vermont	4	267,100	158	143	1	....	10	10	2 10	1 35	57,828	74,241	171,328
Virginia	8	254,700	577	403	....	30	10	10	2 10	1 10	172,726	259,150	538,956
West Virginia	4	42,000	118	82	....	1	10	10	2 25	1 15	38,800	25,871	74,762
Wisconsin	12	747,500	995	816	....	14	10	9	2 35	1 30	440,864	737,878	1,411,201

SIZE OF SHOPS IN ENGINE-BUILDING.—There are three classes of establishments which merit consideration in respect to engine-building. In the first the manufacture is pursued in connection with boiler-making, which often constitutes a large portion of the work. In the second it is a manufacture solely of engines and kindred machinery. In the third we have a small class of factories whose facilities are exclusively devoted to the production of the smaller engine parts, such as governors and valves. Of the two first classes we make the following comparisons by size of shops rated in average numbers of operatives. These figures are the averages for all the shops of the kind in the United States excepting a few in which the work is of a special or involved character:

Engines and boilers.

Operatives in shops.	PER OPERATIVE.			
	Product.	Capital.	Material.	Labor.
100 and over	$1,584	$813	$897	$438
50 to 100	1,562	1,324	720	470
10 to 50	1,535	979	698	469
Less than 10	2,150	863	1,095	510

The increments of value of product above material are $687, $842, $837, and $1,055 for the several classes in the order stated.

Engines and machinery.

Operatives in shop.	PER OPERATIVE.			
	Product.	Capital.	Material.	Labor.
100 and over	$1,365	$951	$652	$504
50 to 100	1,275	1,250	495	465
10 to 50	1,355	1,001	592	432
Less than 10	1,509	1,278	595	477

The increments of value of product above material are $713, $780, $763, and $914 for the several classes in the order stated.

The following comparison is also made between factories engaged in the manufacture of steam-valves, steam-gauges, and governors:

	PER OPERATIVE.			
	Product.	Capital.	Material.	Labor.
Steam-gauges	$1,638	$1,255	$720	$519
Steam-valves	2,520	3,240	1,337	468
Governors	1,589	1,105	674	444

In the manufacture of governors we have an example of the manufacture of small iron parts; in gauges and valves more generally of small brass parts. The small iron work requires less capital and has a smaller value of material and product per operative than the brass work. The manufacture of steam-gauges is a finer class of work than the manufacture of steam-valves. This is exhibited in the relative costs of labor, and in the fact that the value of material is increased about 55 per cent. in the former against 47 per cent. in the latter process of manufacture. The manufacture of steam-valves is a more highly organized work, employing large capital, and enabling much larger quantities of material to be handled per operative than that of steam-gauges.

The manufacture of engines and boilers together may be expected to present some extremes of comparison as one or the other of these two classes of work preponderates. The largest shops (100 operatives and over) present a small showing of capital per operative, whether compared with shops of similar size in boiler-making or in the next class of engine- and boiler-making taken together. It may be said that engine-building usually requires a heavier investment in real estate and machine plant than boiler-making, while when both manufactures are united in one system a large and expensive establishment is inevitable. Such an establishment with a double purpose costs relatively more in investment per operative for a small than for a large number of operatives. But the statistics do not necessarily indicate any such industrial cause, because there are certain variations in the returns of capital which seem scarcely warranted by any basis of comparison. Thus for the largest class of works we find the capital per operative ranging in engine-building from $166 to $3,350, in engine- and boiler-making from $125 to $1,818, and in boiler-making from $200 to $1,500. These are the returns as made, but such extreme figures are exceptional in the returns.

In the class of work represented by shops with less than ten operatives each, jobbing, repairs, and general mill-work have a large influence. The cost of labor is therefore high, a much greater increment of value is given to the materials, and the product per operative is of much higher value than in any other class. Doubtless the value of the product in engines and boilers per operative for the first class, $1,584, represents in quality and quantity much more machinery than the greater value per operative for the fourth class, $2,150. The higher valuation of job work and of work in small shops remote from manufacturing centers exercises upon the financial statistics an influence similar to that of the most effective work and the highest output for the labor in the large shops. The small shops are so much scattered and have so little uniformity of work that there is no strong competition, while the large shops, depending often upon remote markets, are in active competition, which tends to reduce the valuation of the product.

SIZE OF SHOPS IN BOILER-MAKING.—In a comparison of a large number of shops rated by numbers of operatives we obtain the following figures per operative:

Operatives in shop.	PER OPERATIVE.			
	Product.	Capital.	Material.	Labor.
100 and over	$2,770	$1,253	$1,856	$425
50 to 100	1,248	516	618	424
10 to 50	1,708	735	1,026	431
Less than 10	1,849	707	857	480

So far as size of boiler-shop is concerned, these figures seem robbed of significance by the preponderance of other considerations, viz, locality, quality and size of work. It would appear that only in shops of the largest size do the increased product and capital and the material handled per operative stand out in spite of considerations other than size of shop. In the above averages the increments of value of product above material are $914, $630, $682, and $992 for the several classes in the order stated.

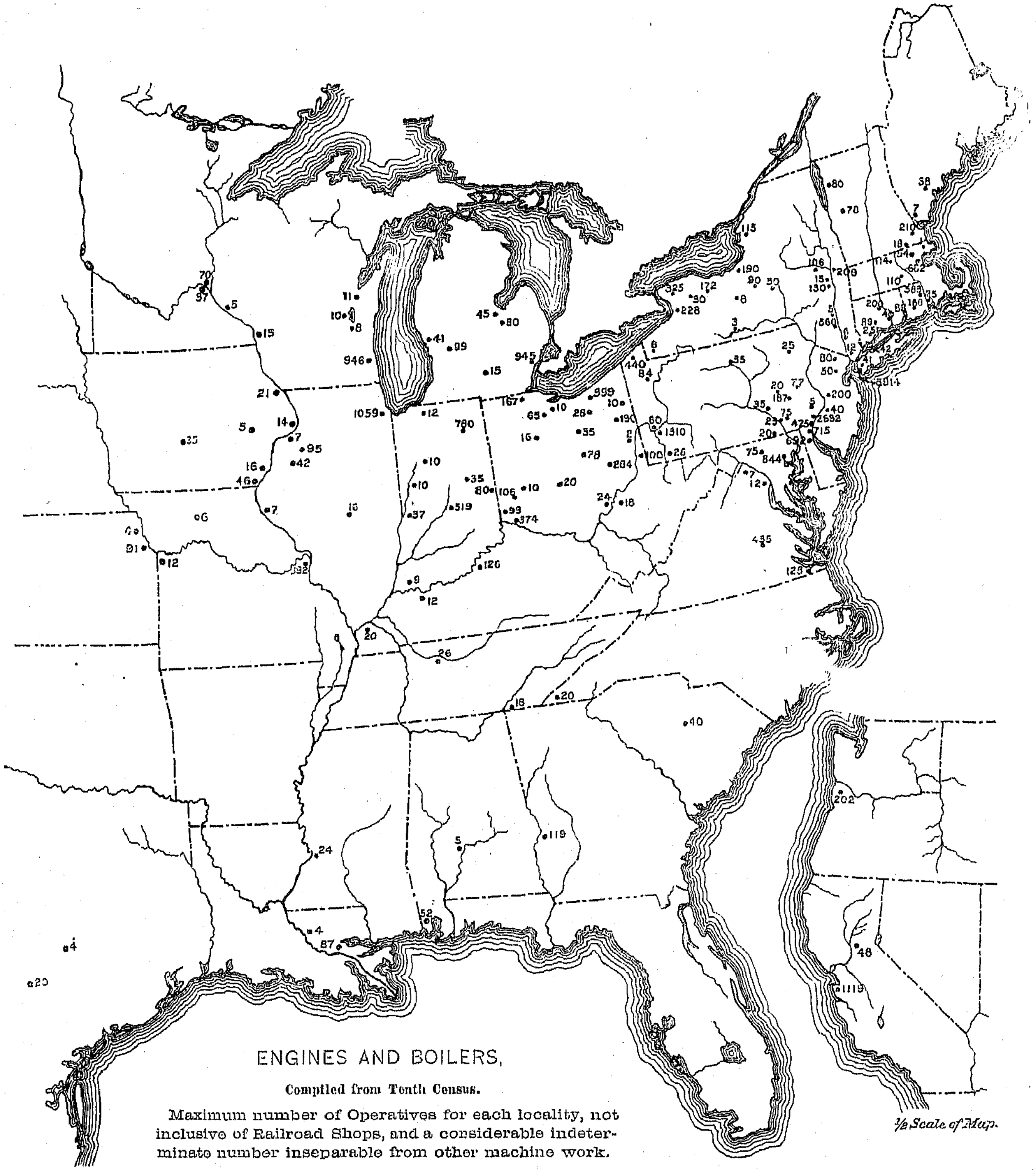
A few words will explain any apparent inconsistency in the order of the figures. Something of this is due to locality. Values are upon a sliding scale for the different sections. Nominally labor costs least in the middle states, Maryland, Virginia, Indiana, and Ohio. In New England it is rated higher, and in the west ranges still higher, being highest in California and in the sections of the south and west remote from centers for the manufacture of machinery. Coal is cheapest in Pennsylvania, West Virginia, Missouri, Kentucky, Ohio, Indiana, Tennessee, Delaware, New Jersey, Maryland, Virginia, and New York, about in that order. As compared with its cost in Pennsylvania we may say roundly that it is more than doubled in Massachusetts, trebled in Minnesota and Alabama, and more than quadrupled in California, that is, taking averages of the iron manufacturing sections of entire states for comparison. The cost of iron is determined less by geographical position than by commercial demand. Its cost of transportation for the same value of material being small as compared with coal, its cost usually varies only a few dollars a ton for all large manufacturing centers from Boston to San Francisco.

Boiler-shops, with fewer than 10 operatives each, will chiefly be found remote from large manufacturing sections. Labor is costly in two senses, both in the nominal rate charged and in the inefficiency of its application, there being, since competition is sluggish, little incentive to obtain the most economical results. Here, then, we find the cost of labor a large element of the value of the product. Materials are also expensive, but as much of the work is in jobbing and repairs, the cost of new materials appears relatively small. The investment may be intrinsically small, but high rates of interest, coupled with the imperfect and partial employment of facilities, causes the latter to appear costly when compared with the value of the product. For the same product per operative the cost of facilities is nearly double that in the average of the larger shops.

In boiler-shops with from 10 to 50 operatives labor is both nominally less in cost and more advantageously applied. The skilled labor is often of a higher grade, but more common labor is utilized. The work is more continuous, less of it is in repairs, and a greater value of material is employed, but the falling off in the cost of facilities per operative is so great as to cause a falling off in the gross value of the product per operative.

In boiler-shops with from 50 to 100 operatives, labor costs still less, but the advantage is due to the better disposition of large bodies of workmen rather than to the introduction of costly labor-saving facilities. The cost of material handled per operative is relatively small. This appears anomalous, but the number of shops averaged is comparatively small, and a number of these are occupied in the manufacture of small boilers and heaters and variety work involving castings. The average grade of the work in this class is lower than the general average of boiler work, there being, per operative, less capital investment, less expensive facilities, less cost of material, and less cost of labor, all indicating a small class of work.

In the largest boiler-shops, of over 100 operatives each, the facilities are much more costly. They are adapted to handle large work rapidly, and the cost of material handled, per operative, is much greater than in the smaller shops. They are adapted to save skilled labor, and although some labor of the highest skill is employed, these facilities, as well as the necessity of a larger proportion of common labor to move and handle the heavier work, operate to reduce the average of wages paid. The product per operative is greater than in the smaller shops, and



ENGINES AND BOILERS,

Compiled from Tenth Census.

Maximum number of Operatives for each locality, not inclusive of Railroad Shops, and a considerable indeterminate number inseparable from other machine work.

½ Scale of Map.

exclusive of returns of work for repairs, the increased value given to the material is greater per operative than in the small shops. This is simply due to the employment of the larger investments of capital necessary in handling heavy work.

While if the work were of a uniform character for all sizes of shops we might expect a steady gradation of the industrial factors, each class cited does in fact present most strongly a special character of work: the smallest, repairs; the second, medium; the third, light, and the fourth the heaviest work.

DISTRIBUTION OF ENGINE- AND BOILER-SHOPS.

REMARKS ON THE MAP.—The number of operatives employed is of course no exact criterion of the product, but may serve to indicate it in a general way. It should be borne in mind that the important manufacture of locomotives (with the work of locomotive repair shops) and of steam fire engines and pumps are not included in the figures, but it is inevitable that the manufacture of machinery in connection with engines should be more or less included. In a few cases, where engine-building is associated with ship- and bridge-building, an effort has been made to separate by estimate the proportions of the distinctive kinds of work, these being so far merged in the actual economy of the business that only estimates are available.

While we may see from the map how notably the manufacture of engines and boilers indicates the place and the importance of general manufacturing interests, in each section the manufacture has its predominant characteristics which deserve to be noted.

In New England the manufacture of engines and engine parts predominates, and it is estimated that six-tenths of the whole number of operatives are engaged in this work against four-tenths engaged in boiler work. In Boston, especially, the manufacture of governors, valves, gauges and other small parts which go to make up a steam-engine, is pursued as a distinct industry. New England may also be esteemed the birthplace of the automatic cut-off engine, and this class of engines, of fine workmanship and large powers, constitute the greatest item of the manufacture. Farm and portable engines are manufactured, although the small and hilly farms of this section do not permit the extensive use of the former, and this product is shipped mainly to the south. In boiler-making, a considerable and increasing proportion of the product is applied in steam heating rather than for steam power.

In the middle states we may consider that nearly two-thirds of the operatives are engaged in boiler work. In New York city the greater part of the operatives work at marine engines and boilers, and their repairs—no small item—since over one-sixth of the steam tonnage of the country is inspected at this port, and the foreign commerce is even in greater proportion. In Philadelphia, the manufacture of locomotives, not here included, employs a large number of operatives.

The manufacture of marine engines and boilers, with their repairs, constitutes the chief factor of the work along the seaboard as far south as Norfolk, Virginia, while on the great lakes the heaviest part of this work is done at Cleveland, Ohio; Erie, Pennsylvania; Buffalo, New York, and Detroit, Michigan.

The manufacture of automatic engines is pursued by large works in the middle states and in the west, but in the west and south, and especially in the great grain and lumber states, farm engines and portables constitute the largest item of manufacture, and large numbers of plain slide-valve engines are built. In the west the prominence of the industry in a few localities is to be noted as an evidence of the rapid growth of the country and of the great demands of the surrounding sections. In the south, Richmond, Virginia, is the great center for the manufacture of portable and agricultural engines.

Of the great amount of steam power employed upon the Mississippi river and its tributaries, the supply of machinery is maintained mainly at Pittsburgh, Pennsylvania; Cincinnati, Ohio; Louisville, Kentucky, and Saint Louis, Missouri. River and marine service is usually more exacting than land service, and a greater proportion of the work is required in repairs, especially of boilers. Thus, boiler- and repair-shops are found established all along the navigable waters, and it should be noted that many of these rivers are not shown upon the small-scale map. Boiler-making may be considered the pioneer industry. This, with the repairs of river engines, may warrant the establishment of a shop remote from large manufacturing centers. Then, when the surrounding country develops the demand, there is already established a small nucleus of skilled labor and facilities for entering upon the manufacture of farm and saw-mill engines.

In the New England, the middle, and the more populous western states, the division of the industry is notable, engines and boilers being built in separate shops and under separate management, and separate factories existing for the manufacture of the smaller parts. This is distinct from the practice of small shops along the river courses in which boiler-making, with engine repairs, is the rule, because the demand does not warrant shops large enough to invest in facilities for the general manufacture of engines. Then, between the two kinds of work there is a great cementing bond in the manufacture of portable engines, in which boilers and engines being assembled together are usually manufactured under one management. While small portable engines are turned out in quantities with uniform parts, as we might say, almost like pistols, it is obvious that in the manufacture of the largest blowing, pumping, and marine engines no such methods are available. In these the work is done by special contract from the designs of special engineering skill.

In the southwest (the Mississippi valley) and upon the Pacific coast the manufacture of boilers occupies nearly seven-tenths of the whole number of operatives. This is largely due to the fact that the marine engines employed are to a great extent manufactured on the Atlantic seaboard for the Pacific service, and at Pittsburgh, Cincinnati, and other northern river points for the whole Mississippi valley. But in the northwest, the manufacture of steam-engines being inevitably associated with that of farm, sawing, and milling machinery, the proportion of boiler work appears relatively smaller, averaging perhaps 40 or 50 per cent. of all, rating by numbers of operatives employed.

LABOR.

CALCULATION OF PERCENTAGE OF SKILLED LABOR.—A rule has been employed in deriving the percentage of skilled men in the industry as follows:

A being the average daily wages for all, that is the wages paid in a year divided by the average number of men employed and by 300, B the stated wages per day for skilled, and C for unskilled labor, and x the percentage of skilled men, then $100\ A = Bx + C(100 - x)$ and

$$x = 100 \frac{A-C}{B-C}$$

whence we have the rule: Deduct the wages for unskilled from the wages for skilled labor and from the average daily wages, and divide 100 times the latter remainder by the former. Three hundred days are taken instead of 313 to compensate in some degree for lost time not returned.

The results obtained are of interest, but not entirely conclusive. In the returns the time is sometimes stated as short, and the average number of hands is given for the running time only, and not for the full year, nor with any reduction of average on account of lost time.

REPORTED TIME OF LABOR.—In the majority of the states either full time or an average of over 99 per cent. of full time is returned, the percentages being rated not by factories but by numbers of operatives. In the remainder the averages are about—

	Per cent.		Per cent.
Connecticut	91	Missouri	95
Pennsylvania	97	Kansas	97
Maryland	98	Ohio	95
North Carolina	87	Indiana	97
Mississippi	80	Illinois	98
Louisiana	93	Iowa	95
Kentucky	96	Colorado	86

A SOURCE OF ERROR.—Some cases are not fair criteria on account of the average number of operatives being overstated. The statements returned for average numbers of operatives are rough approximations, the numbers of hands employed varying from time to time. It is to be expected that they will not always be consistent with the stated time and daily wages paid. Shops which run full time the year around often have for a time a short number of hands on account of break-downs, changes, repairs, strikes, short orders, severe weather, sickness of men, and the like, and the proprietor has not often the averages of these changes calculated to a nicety to return to the census agent. In like manner piece-work and overtime-work (paid perhaps at increased wages) may disturb averages based on regular full time. The tendency being mainly in one direction, error is not eliminated in the larger averages.

The usual tendency of manufacturers in making returns is not to shrink the apparent size of their establishments by allowances for temporary and partial stoppages. There is a certain pride in the employment of a large number of men, and the general average is belived to be over- rather than under-stated, so that the average wages deduced from the statements of average numbers of hands and wages paid will usually be found lower than the actual average wages. This is conspicuously the case in some individual returns of engine- and boiler-works, and doubtless has great effect upon the general showing.

THE PERCENTAGE OF SKILLED LABOR.—The apparent percentage of skilled labor in engine-building and boiler-making calculated by the rule explained, averages for the New England and middle states about 40 per cent., for the southern and western states about 30 per cent., and in the states and territories of the far west about 36 per cent. In some of the southern seaboard states this apparent percentage appears quite low, but it is higher in the southern inland states. In some of the large grain states it is also low, but is as high as 47 per cent. in two of the northwestern states, a percentage exceeded in seven other states and territories, Kentucky, Kansas, Utah, Maryland, Rhode Island, New York, and Oregon.

Average percentages of skilled labor appear ranging from 74 per cent. downward for the several states. The general apparent average is about one-third. In the large engine factories of Rhode Island the average appears at 51 per cent., in those of New York at 48 per cent., and of Wisconsin at 47 per cent.

Three conclusions are very obvious in this connection: First, that the percentage of skilled or highly-paid work is usually greater in engine-building than in boiler-making; second, that it is relatively greater in small than in large shops, and, third, that it is greater for fine and light than for coarse and heavy work. These conflicting conditions entering into general averages in various unassignable proportions deprive such averages of the most definite significance.

The examples furnished by individual shops in which the conditions are quite definitely known will be found of more value, and some such examples will hereafter be cited under the reference to division of labor in shops. The foregoing statements of percentages of skilled labor are of some value relatively, but owing to the fact that such percentages to be true must be calculated from the minimum average of number of workmen, allowing for all lost time, and the usual average stated being probably 15 or 20 per cent. above this minimum, the calculated percentage of skilled labor is very much less than it should be. For the whole country the calculated percentage is estimated to average about half of the actual proportion of skilled labor, which should range from 60 to 80 per cent. of all instead of, as calculated, from 30 to 40 per cent.

DIVISION OF LABOR.—The division of labor in shops may best be illustrated by examples in which some data of the character of the work are given.

A large shop in the west, employing several hundred operatives, has the following division of labor, rated in percentages of the whole number of hands:

	Per cent.		Per cent.
Vise hands	0.080	Blacksmiths	0.056
Other machinists	0.335	Wood-workers	0.052
Molders and core-makers	0.127	Office work, time-keeping, etc	0.060
Laborers in foundery	0.075		1.000
Other common labor	0.125		
Boiler-makers	0.090		

About 63 per cent. of the labor in the foundery is skilled. Some milling, woodworking, and other machinery is included in the product of the shop. Boiler-making was a minor portion of the work, perhaps one-fifth or one sixth, counting all the labor involved. During the year the average attendance of men was 70 per cent. of the maximum. The shop was running upon the average only 70 per cent. of full time.

In the above showing, the skilled and high-priced labor constitutes a large percentage of the whole number of hands, viz., nearly 80 per cent. The variety of work done is great. Estimating by the rule previously cited, with allowance for lost time, we find average wages paid per day, $2 04, stated average wages for skilled men being $2 25, and for unskilled, $1 35, whence we have a showing of 76 per cent. of skilled men, which accords perfectly with the results of the more detailed inquiry. The importance of full time and steady work, and the disturbance which a slight variation in the accuracy of statement of average number of operatives may cause in the calculation of average wages is set forth in the following table from the undoubtedly reliable returns of this establishment:

Rates per annum per operative.

Number of operatives.	Capital.	Wages.	Materials.	Products.
Maximum	$1,200	$300	$460	$1,200
Average	1,715	428	657	1,715
Average at full time	2,449	612	923	2,449

The proportionate value of products to materials for the shop in question indicates that its chief work is the manufacture of a fine class of engines and machinery. If we assign the common labor and clerical labor in suitable proportions to the various distinct departments, we obtain in round numbers the following exhibit of the allotment of labor:

	Per cent.		Per cent.
Machinery, fitting and assembling	50	Blacksmithing	7
Foundery work	21	Wood-working	6
Boiler-work	16		

It is of interest to compare with the foregoing the division of labor in another large shop in which the element of boiler-making is excluded, while the engine work is of a heavier character, some milling and other machinery being included in the product:

	Per cent.		Per cent.
Machinists	35	Wood-workers	10
Molders	10	Pattern-makers	2½
Core-makers	4	Office, watchmen, and teaming	8
Laborers in foundery	17½		100
Other common labor	9		
Blacksmiths	4		

The proportion of wood-workers is large, because the manufacture of mill machinery with wood framing is included, but the most notable feature is in the increased proportion of laborers in the foundery, while the proportion of molders and core-makers is scarcely increased. This is simply because the work deals with heavier castings. Blacksmithing also is required upon fewer and heavier pieces. In the foundery only 44 per cent. of the labor is skilled. Full time is reported, but the average is only 84 per cent. as great as the maximum force employed. The skilled and high-priced labor appears less than 74 per cent. of all. Applying the rule for calculating this percentage from the average number of men, and the wages paid, we have: Average wages paid per day, $1 80; stated average wages being for skilled men, $2, and for unskilled, $1 25, whence we have a showing of 73 per cent. of skilled men, which accords with the detailed results. The rates per annum per operative are for the actual average number of operatives: Capital, $887; wages, $539; materials, $929; products, $1,685, the relative values of products and materials indicating heavier work than in the preceding case. A somewhat smaller shop in the same locality, and engaged in the manufacture of a cheaper grade of engines, has the following statistics: Full time is reported, and the average number of operatives is 96 per cent. of the maximum; per annum per operative, capital amounts to $1,000; wages, $600; materials, $1,080; products, $2,200. The calculated proportion of skilled labor is 60 per cent., the average wages being $2; wages for skilled men, $2 50; unskilled, $1 25. The work embraces less variety than the other, and being more stereotyped, a smaller percentage of skilled labor is required.

The following statistics are given of five large shops in the east, all making automatic engines of large size. All report full time and a daily period of ten hours' work throughout the year:

	1.	2.	3.	4.	5.
Percentage of average to maximum number of operatives...	70	81	100	100	90
Per annum per operative:					
Capital...	$1,205 00	$477 00	$3,253 00	$1,000 00	$166 00 (?)
Wages...	687 00	415 00	532 00	500 00	317 00
Material...	439 00	1,107 00	1,833 00	500 00	417 00
Product...	1,205 00	1,833 00	1,482 00	1,200 00	833 00
Average wages:					
Skilled labor...	2 75	2 12	2 50	2 50	2 00
Unskilled labor...	1 50	1 25	1 35	1 25	1 25
Apparent average wages paid...	2 29	1 38	1 77	1 66	1 05
Apparent per cent. skilled labor...	63	15	37	67	(a)

a No result.

By reason of overstatement of the average numbers of operatives the calculated average wages paid appear too low in 2, 3, and 5. The apparent percentages of skilled labor are too low in 2 and 3, and for 5 the result is absurd on the same account. Correction would of course alter the financial showing per operative. Shop 1 is devoted to very heavy contract work. Shop 2 makes smaller engines to stereotyped patterns, and turns out a much greater product per operative. If in shop 2 the time or number of operatives had been 20 per cent. overestimated, we would have: Capital, $572; wages, $495; material, $1,436; product, $2,200 per operative; apparent average wages, $1 65; skilled labor, 46 per cent. of all. Twenty-three per cent. overestimate would give 52 per cent. skilled labor, and so on. The shop in question is well known; its work is of a fine character; its departments are similar to those of shops already cited, and the proportion of skilled labor is necessarily large, probably as much as 60 per cent. of all. The return of skilled wages also shows a low rate. In only four state averages is it lower, and for the section in which the shop is located it is very low. The error in this and in similar cases is easy to place. It is due simply to overstatement of average number of operatives on a basis of full time. It is not that such returns are not rendered in good faith. The usual attendance of hands is stated when the shop is running at its normal capacity. The full usual time is stated. Stoppage and half-time are stated in units of months. But if we take the time-keeper's book we find here and there a few days' or weeks' shut down of a part of the works, or the normal capacity has not been as well maintained as is supposed, and the actual percentage of time to be deducted on this account may be surprisingly large. The practice of closing an hour earlier on Saturday makes $1\frac{2}{3}$ per cent. difference. Two weeks' shut down makes 4 per cent. difference, and an hour a day short for half the year, 5 per cent. That the mean yearly average is overstated in the aggregate is plainly indicated by three things: First, inconsistency in the calculated proportion of skilled labor, as shown by many special inquiries; second, the value of the product per operative, *which has been calculated for every shop*, and often appears too low; third, the number of large shops in which (as in 3 and 4) the average number of operatives is returned as equal to the maximum. The return is so made by about one-third of all the shops.

I will cite the statistics of three more engine-building shops, which present fair examples; 6, of a large shop building automatic engines; 7, of a shop building marine engines exclusively, and, 8, of a smaller shop, this last being on the Pacific coast.

	6.	7.	8.
Percentage of average to maximum number of operatives	100	100	100
Per annum per operative:			
Capital	$1,317 00	$500 00	$625 00
Wages	452 00	480 00	702 00
Material	643 00	400 00	250 00
Product	1,327 00	900 00	1,375 00
Average wages:			
Skilled labor	1 90	2 00	3 50
Unskilled labor	1 15	1 25	2 00
Apparent average wages paid	1 50	1 60	2 64
Apparent per cent. skilled labor	53	53	57

All return full time and ten hours a day throughout the year.

Of the division of labor in three of the largest shops in the country in which the manufacture of boilers and engines is combined under one management, the following tabulation is made:

	a.	*b.*	*c.*
	Per cent.	*Per cent.*	*Per cent.*
Machine-shop	36	34	37
Foundery	30	23	21
Boiler work	16	23	25
Blacksmithing	7	9	10
Office work, etc	7	7	5
Pattern-making	4	4	2

The proportion of skilled labor in the foundery ranges from one-half to three-fourths. The shops are located in the south and west. All employ the most improved tools and facilities, and do thoroughly good work, and all make a specialty of portable engines, building also stationary engines and boilers. Their statistics, as returned, are given as follows, and with them, under the head *d*, the statistics of a smaller shop in New England, in which the division of labor is similar, but with a greater proportion of boiler work:

	a.	*b.*	*c.*	*d.*
Percentage of average to maximum number of operatives	100	100	91	100
Per annum per operative:				
Capital	$777 00	$350 00	$625 00	$961 00
Wages	444 00	350 00	312 00	654 00
Material	555 00	402 00	781 00	2,212 00
Product	1,222 00	900 00	1,250 00	3,173 00
Average wages:				
Skilled labor	1 75	2 00	1 75	2 75
Unskilled labor	1 00	1 00	1 00	1 60
Apparent average wages paid	1 48	1 17	1 04	2 18
Apparent per cent. skilled labor	64	17	5	54

The actual percentage of skilled labor is probably not less than 60 per cent. in these cases. All return full time, and ten hours is the customary time of day's labor, but for half the year *a* runs at eight hours and *d* at nine hours a day, for which allowance is made.

Not so much is to be said in regard to the division of labor in shops devoted to the exclusive manufacture of boilers. In this we may usually estimate about 50 per cent. for the skilled boiler-making crafts, 20 per cent. for laborers and helpers in boiler-making, 20 per cent. foundery work for the castings involved, and 10 per cent. for the blacksmiting and other work. Sometimes the shop work is confined to the working of sheet-steel and iron, foundery work not being included. In the strict work of boiler-making we may for heavy work estimate riveting and calking to require 54 per cent. of the labor; flange-turning, and the most skilled work of boiler-making, 18 per cent.; common labor, rivet heating, and helping, 28 per cent. There are usually about half as many rivet-heaters as riveters. The rivet-heaters are not infrequently boys, the work being both light and unskilled.

Of the statistics of boiler-shops, the following six examples may be taken as exhibiting the character of the returns. The real proportion of skilled labor may be taken at between 50 and 70 per cent., possibly less than 50 in tank work, and a correction of the actual returns, as here given, may be based on this understanding. The shop *a* makes marine boilers, and is located on the Pacific coast; *b*, located in New England, makes large stationary boilers of a uniform type; *c*, located in the west, makes river-boat boilers mainly, and *d*, also in the west, is a large shop, making stationary and portable boilers. A shop making tanks and boilers, mostly a low grade of work, is represented by *e*, and a small shop in the south, devoted to boiler-making and repairs, by *f*:

	a.	*b.*	*c.*	*d.*	*e.*	*f.*
Percentage of average to maximum number of operatives	53	100	46	80	100	100
Per annum per operative:						
Capital	$520 00	$1,200 00	$750 00	$2,727 00	$952 00	$421 00
Wages	789 00	600 00	932 00	655 00	261 00	333 00
Material	1,052 00	2,000 00	2,315 00	1,704 00	936 00	526 00
Product	2,000 00	3,200 00	3,592 00	2,500 00	1,248 00	1,579 00
Average wages:						
Skilled labor	3 50	2 75	2 50	2 50	2 25	2 50
Unskilled labor	2 00	1 50	1 75	1 50	85	1 00
Apparent average wages paid	2 97	2 00	3 11	2 18	87	1 11
Apparent percentage skilled labor	65	40	(*a*)	68	02	07
Time returned	Full.	Full.	¾ to full.	Full.	Full.	⅝ to full.
Average time, daily labor	9½	10	10	10	10	9½

a No result.

The showings of *e* and *f* are due to the usual element of overstated average time. The peculiar showing of *c* is due to unspecified overwork paid at extra wages. This of course swells the value of the product.

RATES OF WAGES.—As there are usually several grades of wages paid for skilled labor, the amount stated as the wages of skilled labor is an average given by the manufacturer, and obtained from several rates. In engine-building, ordinary labor was not usually paid at less than $1 per day at the time of taking the Census, exceptions being mainly the labor of children or youth or other labor less than that of full hands, especially in small shops remote from manufacturing centers. In the south we find colored laborers employed in the founderies and blacksmith shops, not in the skilled crafts, but only as helpers and blacksmith's strikers.

The highest average wages are paid in the small, isolated repair shops, but in these the work is less uniform than in the large shops, while in their localities the purchasing capacity of money is often smaller for the same amount than near the large manufacturing centers.

Since 1870 rates of wages appear upon the average to have fallen off about 12 per cent., but it should be remembered that although the intrinsic worth of the product is now probably greater per operative than in 1870, its commercial value has fallen off about 15 per cent. while rated per operative the difference between the value of product and the cost of materials and labor—a difference which may be taken to include running expenses, avails, and interest on capital investment, has fallen off about 30 per cent. Quality considered, the same amount of money would have purchased perhaps 20 to 25 per cent. more steam machinery in 1880 than in 1870, although the violent fluctuations in the cost of iron during 1880 were enough to impair the accuracy of any general statement. There can, however, be no doubt but that the general purchasing power of wages paid in 1880 was greater than in 1870.

There is one evidence of the state of manufacture in the various sections which deserves to be noted here. It is in the relative rating of skilled and unskilled labor. Positively, the rates may furnish but an uncertain gauge of the skill or of the comforts of the workman, since $3 50 a day, with irregular time of work in one section, may yield a smaller living return than $2 50 a day with steady work and low cost of living in another section. But when we note the relative rates for skilled and unskilled labor we see at once that in those sections in which mechanical facilities are most fully developed and manufacture is pursued upon the largest scale, the wages of skilled mechanics are sometimes no more than once and two-thirds the wages of unskilled workmen, while in small shops with few facilities and little organization, the rates for skilled men are sometimes two, three, four, or even five times as much as for the unskilled. In the former cases the unskilled labor is of a higher class than in the latter.

The manufacture of machinery differs from the manufacture of iron in its cruder forms, and to some extent also from boiler-making, in the influence which it exerts upon the condition of the laborer. In the latter, as in some other classes of manufacture, improved and enlarged plants tend mainly to increase the number of laborers of little skill. The machine often takes the place of skill in a considerable body of workers. But the manufacture of steam engines and other machinery is so various in its processes and so complex in its organism that its improvements will be found to stimulate intelligence.

For the several sections we find that in numerical value the wages of the skilled men are slightly more uniform than the wages of the unskilled, but in intrinsic worth—that is, in local purchasing power—the wages of the skilled men are the more uniform than those of the unskilled. The range of wages of skilled men is from $4 50 to $1 90 ($3 to $2 25 usual). For unskilled men the range of wages is from $2 35 to 50 cents ($1 40 to $1 usual). Taking the averages of the shops of large sections, the ratio of skilled to unskilled wages is about 1.70 to 1 for New England, 1.75 to 1 for the west and northwest, about 2 to 1 for the middle, and about 2.15 to 1 for the southern states. This average is taken by states, and the influence of small shops is offset against that of large, making the ratio too great. Thus, for the southern states, if the average ratio were taken proportionately to the numbers of operatives in the shops, the influence of the large shops in Maryland and Virginia would bring the average ratio below 2. But the lowest ratios occur in the large manufacturing centers, where skilled labor is most demanded and best appreciated. In these places the intrinsic worth of the wages of skilled men is relatively high, and as the value of the wages of unskilled men approaches nearest to that of skilled men in these same localities, there is greater variation in the true purchasing value of the wages of unskilled men in the various sections than would appear from the numerical rates of wages.

In engine building, as in some kindred industries, the higher development of the work by more productive methods elevates alike the intelligence required and the pay and living condition of the common laborer. Nor should it be forgotten that common labor, unlike skilled craft, is interchangeable among all industries in any given section of the country. Such tendencies then are to elevate common labor, not in special or protected industries, but as a whole, and it is unquestionably so elevated in this country. Thus, while the manufacture of agricultural machinery has released great populations from the necessity of tilling the soil, the wages of the farm laborer are increased by the drawing of labor into manufactures. The increased efficiency and the increased returns are shared by nearly every class of labor so long as the country is, as at present, in a growing state.

I conclude this consideration by giving the following averages for large numbers of shops making, respectively, engines and boilers, engines and machinery, and boilers exclusively. The average number of operatives is reduced to a uniform scale of ten hours' a day labor, and full time during the year so far as the lost time is returned, but it is still considered that there is an average of between 10 and 20 per cent. of lost time, for which no allowance is made, or, in other words, the nominal number of hours' labor being ten hours a day, a strict allowance for all lost time would probably reduce the average to something less than nine hours a day, a fact to be borne in mind when comparing rates of wages with those of foreign shops in which the men have to work a greater number of hours a day.

Of the shops engaged in this manufacture in the United States, only five report twelve hours' a day labor, and in these this rate is maintained only half the year. It may then be said that the averages for wages of skilled and unskilled labor are based upon ten hours' a day labor, but I have based the average daily wages paid at the rate of eight and one-half hours' labor for the stated average number of operatives. This may seem a large reduction, but even this is not large enough to account for the proper proportion of skilled labor in the large boiler-shops.

BOILER-MAKING.—Nine large shops, with 1,517 operatives, show an average rate of wages for skilled labor of $2 52; for unskilled, $1 24; ratio of wages of skilled to wages of unskilled labor, 2.03. Average wages paid at ten hours, $1 53; eight and one-half hours, $1 30; percentage of skilled labor, 22 per cent. (underestimated). Ninety-seven smaller shops, with 2,006 operatives, show an average rate of wages for skilled labor of $2 36; for unskilled, $1 35. Average wages paid at ten hours, $1 94; at eight and one-half hours, $1 65; ratio of wages of skilled to wages of unskilled labor, 1.75. Proportion of skilled labor, 58 per cent.

BOILERS AND ENGINES.—Seventeen large shops, with 3,070 operatives, show average wages: skilled labor, $2 21; unskilled, $1 27; ratio, 1.74. Average wages paid at ten hours, $1 78; at eight and one-half hours, $1 51. Proportion of skilled labor, 54 per cent.

Eighty smaller shops, with 1,885 operatives, show average wages: skilled labor, $2 40; unskilled, $1 30; ratio, 1.85. Average wages paid at ten hours, $1 93; at eight and one-half hours, $1 64. Proportion of skilled labor, 57 per cent.

ENGINES AND MACHINERY.—Fourteen large shops, with 3,213 operatives, show average wages: skilled labor, $2 21; unskilled, $1 27; ratio, 1.74; by a coincidence, the same as in the manufacture of boilers and engines in the large shops cited. Average wages paid at ten hours, $1 98; at eight and one-half hours, $1 69. Proportion of skilled labor, 75 per cent.

Eighty-three smaller shops, with 2,313 operatives, show average wages: skilled, $2 32; unskilled, $1 25; ratio, 1.85. Average wages paid at ten hours, $1 87; at eight and one-half hours, $1 59. Proportion of skilled labor, 58 per cent.

The arbitrary time allowance taken causes the proportion of skilled labor to appear smaller than probable in most of the foregoing cases. The object in taking averages of selected cases is, so far as possible, to exclude anomalous conditions and to express general and ordinary conditions, for the manufacture of engines and boilers is associated with many other manufactures, from bridge iron to hardware and agricultural woodwork. There is a growing tendency to build machinery with a steam cylinder to each machine. By this arrangement power is advantageously applied, and does not run to waste in transmission, nor when the machine is at rest. Of this, stone-crushers, calendering-machines, nail- and freightage-machines, hammers, drops, trips, windlasses, and many kinds of special machinery, may be cited as examples, and these will suffice to indicate how impossible it is to make a clearly defined separation between engine-building and other machine work.

THE MANUFACTURE OF LARGE AND SMALL ENGINES AND ENGINE PARTS.

The following observations upon the manufacture of steam-engines are not founded upon the practice of any particular builder or manufacturer, but upon a mass of data often more or less contradictory and derived from many sources. There is in the manufacture a great variation in the product and a considerable variation in the methods pursued, so that there must be many exceptions to any general statement. In bids for specified machinery in competition, prices will often range very widely, sometimes as 1 to 2, or more, and general statements of so varied a manufacture as steam-engine building are, it must be confessed, a somewhat vague specification.

In many shops there is a highly developed system, and if in some of them the productive operations are more or less merged or confused, some knowledge and principles of value may yet be derived from their study.

The steam-engine is made up of metal parts of great variety in shape and finish. The great weight of the parts is of cast-iron, but some important parts of simpler forms are forged. In casting, the element of cost which is most noticeable is the size of the piece, small castings costing more by the pound than large. It has been suggested that a formula might be utilized in which weight of castings and number of pieces should so enter that the proper charge for any specified work of casting might be thereby deduced, and it may even be said that the methods of estimate sometimes employed by founderymen are tantamount to the use of some such formula. Peculiarity of form requiring extra care in moulding is also an element which much be considered in estimating the cost of castings. The next element of cost is in the machine-tooling, which differs with the surface machined and with the accuracy of work, the facing of a slide-valve, for example, costing far more for the area surfaced than such work as the planing of the frame feet on which the engine rests. In ordinary practice the machining of small pieces for similar areas surfaced costs vastly more than the machining of large pieces, on account of the time lost in resetting the work, which in many classes of shop-work is two, three, or more times the period during which the tool operates upon the work. For example, to bore out in 3- by 4-inch cylinders the same surface as would exist in a 90- by 144-inch cylinder would require the small work to be reset and centered over a thousand times. The cost of assembling is not closely assignable, and the cost of investment, teaming, common and clerical labor, etc., can only be estimated in a lump percentage. In these last items chiefly reside the opportunities for profit due to careful management and effective business system.

Let us now mentally place before us an engine of an ordinary style and size, a horizontal slide-valve engine, with a 10- by 20-inch cylinder, an engine commonly rated at 30 horse-power nominal, and which will realize that power with fair economy under proper conditions of speed and pressure. Such an engine has a cylinder-volume of 0.91 cubic feet; it will weigh without auxiliary irons and fitting between 5,000 and 7,000 pounds, and will cost between $600 and $800.

Its parts are very numerous if we enumerate every pin, bolt, and washer, but those which constitute the principal elements of weight and cost may be easily considered. I divide them for convenience of consideration into three classes, heavy, medium, and light. In the first I place the fly-wheel, the frame, and the disc-crank and main shaft together, the engine considered having a disc-crank which, like the fly-wheel, assists in the regulation of the speed. The cylinder (shell), which weighs about 325 pounds, might be placed in this class, but as the considerable proportion of tooling upon it brings it more into keeping with the next class, it is placed there, and with it the steam-chest, slide-bracket, cylinder-heads, piston, outboard bearing-block, main bearing-cap and quarter-boxes, connecting-rod, throttle-valve, and large bolts. The cylinder shell usually weighs more in proportion to the weight of the engine in the small than in the large engines, but some other pieces classed with it increase in weight more rapidly than the average of the engine parts as we pass from the smaller to the larger sizes of the engine. As comparatively light parts are classed the numerous components of the governor, the valve-glands and slide-guides, piston-rod, eccentric, strap, bolts and pin, oil-cups, packing-rings, shoes, springs, crank and cross-head boxes, liners, straps and keys, main and valve cross-heads, slide-valve, governor-pulley, eccentric-rod, and piston-glands and bolts.

The parts classed as "heavy" are estimated to weigh about 4,600 pounds; as medium, about 640 pounds (about half of which is in the cylinder); as light, about 140 pounds, making their relative weight about 85½, 12, and 2½ per cent. of the total weight respectively. But in the estimate of the values of these parts, with an added percentage for general and contingent expenses, we may consider that the heavy parts represent 56 per cent., the medium parts 24 per cent., and the light parts 20 per cent. of the value of the engine.

For the same surface machined the work upon the fly-wheel costs less than upon any other part, because the cut is a long continuous one, and balance-wheels and pulleys are such staple articles that labor may be employed to the best advantage upon them, and without the diversion of changing the kind of work, which is always fatal to a high efficiency. Precisely the reverse is true of the small engine parts, which, not being required in large numbers, are often made at a disadvantage in respect to economy.

The cost of material and casting ranges from about 2½ cents for the large to 3½ cents for small iron castings. Cored work commonly commands a higher rate than castings made without cores, and contracts are often let at an average price for all castings, large and small. Wrought-iron parts and large parts of machine steel (such as shafts) cost 2½ to 3 cents a pound, but forged crank-shafts with return-cranks have a higher cost, which increases with the size, as does the difficulty of forging. Parts of brass or bronze cost usually from 20 to 30 cents, of malleable iron from 6 to 12 cents, and of cast-steel from 10 to 15 cents a pound, unfinished.

The difference in cost of completed parts by the pound is chiefly in the labor of machining and finishing. The greatest improvement in economy is to be sought here, and wherever iron or steel of manufactured shapes can be utilized, the increased cost of material may be much more than compensated by the decreased cost of work in the shop. The stock for a wrought-iron connecting-rod may weigh 50 pounds and require $10 worth of labor in turning and finishing. A cast-steel rod to take its place may cost four times as much by the pound, but its weight is about half that of the wrought-iron stock, while the cost of machine work is reduced to $5, showing a decided advantage in the use of the costlier material.

Of the cost of work on parts of engines, the figures cited are calculated to convey fair average ideas, and at some time to serve as a significant gauge of future progress. From them there is considerable variation, and one is often surprised in going over actual cases to find how much certain machine-work costs when inefficient methods are employed, and how insignificant the cost becomes when improved machinery is applied. I do not here consider the cost of investment in machinery. An engine part which costs $4 forged at the anvil and finished without special tools, costs only 1½ cents when drop-forged between steel dies and finished by special milling-tools.

For the 10 by 20 engine the pound-costs for machining will be about ½ cent for the fly-wheel, ¾ cent for the frame, 2 cents for the shaft and disc-crank, 2 cents for the cylinder, 8 cents for the eccentric-rod and strap, 10 cents for the piston-rod, 10 cents for the slide-valve, and 20 cents for the connecting-rod. The parts specified as heavy will cost about 2½ cents for material, 1 cent for work; medium, 3½ cents for material, 5 cents for work; light, 4½ cents for material, 30 cents or more for work.

As we pass from the small to the large sizes of engines it is obvious that we will soon reach a point at which the large parts of a small engine would be no heavier than the small parts of a large one, and thus the character of the manufacture changes. For an engine 6 inches diameter of cylinder by 12 inches stroke of piston, called an 8 horse-power engine, the percentages of total weight are about 78, 18, and 4 per cent. for the specified heavy, medium, and light components. For a 20- by 30-inch engine, called 100 horse-power, these percentages may be rated at 90, 8½, and 1½ per cent., respectively. The percentages of total cost were found to be 51, 28, and 21 for the small, against 75, 14, and 11 per cent. for the large engine respectively. The cases were not strictly comparable in regard to some conditions, but the subject can only be treated by approximations.

The variation in the increase of weight of the different components as we proceed from the small to the large sizes of an engine bears upon the question of economy of material, and warrants variations in design for different sizes.

Let us institute a few comparisons on this score, taking a 6- by 12-inch, a 10- by 20-inch, and a 24- by 36-inch engine for purposes of contrast.

Weights of engines.

	6- by 12-inch.	10- by 20-inch.	24- by 36-inch.
	Pounds.	*Pounds.*	*Pounds.*
Weight of engine with fly	1,000	5,700	35,000
Weight of cylinder-shell	107	326	1,676
Weight of main shaft	8	38	314
Weight, in cast-iron, of a solid cylinder equal to the cylinder space	88	408	4,235

Putting the same comparatively, the weights for the small engine being taken as units:

	6- by 12-inch.	10- by 20-inch.	24- by 36-inch.
Engine	1	3.66	23.75
Cylinder-shell	1	3.05	15.66
Main shaft	1	4.75	30.25
Solid cylinder	1	4.64	48.12

It is obvious that a disc-crank suitable for small sizes of engine would add disproportionately to the weight of a long-stroke engine. In parts like the cylinder-shell, whose dimensions are calculated with the addition of a constant quantity to secure sufficient margin for stiffness, the increment provided for rigidity becomes relatively less and less as the cylinders increase in size. In cross-heads and other small parts there is also a surplus of metal in the small as compared with the large sizes. The area in cross-section of bolts for the cylinder-heads varies under similar proportions and pressures about as the weight of the shell, but the cylinder-heads weigh proportionately more in the larger sizes. In the above examples we see that the weight of the main shaft, which is one-thirteenth of that of the cylinder-shell in the 6- by 12-inch engine, has increased to nearly one-fifth of it in the 24- by 36-inch engine, and in larger sizes its weight is relatively much greater. The piston-head is relatively heavier in the larger engines, but the piston-rods and connecting-rods are relatively lighter.

Considering the weight of a cylinder volume as the unit of comparison, the frame and nearly every part of the engine is relatively lighter in the larger sizes, but considering, as understood in the foregoing remarks, the average weight of the engine parts as the basis of comparison, then we have on one side the frame, main shaft, crank, cylinder-heads, piston-head, and usually the fly-wheel, growing relatively heavier, and the cylinder shell and most of the small parts growing relatively lighter as we proceed from the smaller to the larger sizes of engine. The ordinary weight of fly-wheel for the specified engines running at 400 feet of piston speed per minute is as follows, actually and relatively:

	6- by 12-inch.	10- by 20-inch.	24- by 36-inch.
	Pounds.	*Pounds.*	*Pounds.*
Weight of fly	500	2,040	12,000
Relatively	1	4.08	24.00

The necessary weight is of course dependent upon the rotative speed, and is relatively less in short-stroke engines.

As we pass from the manufacture of small to that of large engines, the machine-tooling and workmanship is a continually diminishing element of cost, and the cost of material becomes more and more the chief element. The small parts, upon which much work is done, become relatively lighter and less important, and the work upon the large parts is more continuous, while similar areas of surface are more cheaply machined. We notice this even in the aspect of the shops. Where large engines are built the tools are of course larger and heavier, and the shop space per man is greater. It also appears in the statistics determining the relative costs of labor and material. But while the statistics may enable us to make a shrewd guess as to the character of the work, they are not a certain guide in these respects. The cost of labor is relatively great in work of repairs, as well as in building small engines, while the cost of material returned may be relatively great in the manufacture of small engines by parties who purchase some of the engine parts in a more or less finished state.

COST OF AN ENGINE FRAME.—The following analysis of the elements of cost by the pound of an engine frame finished, weighing about a ton, and worth $210, may be of interest, although it might go without saying that these elements would be more or less varied under different conditions of manufacture. It shows in a very graphic way how the cost of machinery is distributed, about how much goes toward paying for the use of valuable tools, and how much for the use of buildings, supervision, and facilities for obtaining credit, and for marketing and transporting the product. It shows how much goes for the labor of mining and transporting the constituent materials, and how much for such auxiliary materials as files, oil, tools, power, and foundery coal, flux, sand, water, gas, and other contingent expenses, and it shows finally how much goes for labor in the foundery, and for the various kinds of machine-work. It is, to be sure, only an estimate for a single engine part, more or less variable in every condition of cost, and yet the figures are not so far removed from ordinary conditions as to be misleading. The interest on investment and machine plant is divided pro rata by a division of the capital investment among the annual products of that investment:

	Amount.	Amount per pound.
		Cents.
Interest on machine plant	$8 00	0⅖
Interest on other investment	32 00	1⅗
Middlemen's profit in selling	25 00	1¼
Constituent material	35 00	1¾
Auxiliary material and expenses	48 00	2⅖
Foundery labor, 200 hours	40 00	2
Machine-shop labor (*a*)	22 00	1$\frac{1}{10}$
Total	210 00	10½

a Twenty hours fitting and setting up; 15 hours planing; 10 hours filing; 5 hours drilling; 5 hours boring; 5 hours supervision; 15 hours other labor.

It is also to be noted that the value of frame is taken as it exists in the finished engine with its proportionate allowance of cost for assembling and marketing.

RELATIVE COST OF PORTABLE ENGINE PARTS.—In passing from a 6- by 12-inch to a 10- by 20-inch mounted portable engine, we find that the weight is trebled and the cylinder capacity is increased fivefold, while the price is nearly doubled.

While the average cost of parts is nearly doubled, it will be noted that the price of some parts is increased more than twice, while there is little or no change in the price of other parts. This conveys an idea of the relative increase in the cost of manufacture of the several parts.

Taking the prices of the several parts of the 6- by 12-inch engine as units, and comparing with them the prices of similar parts of the 10- by 20-inch engine, we find for the following specified parts the following ratios of cost:

The ratio is 1, or value the same for both sizes, for brake-shaft box, brake-shoes, cylinder-cock, and angle-valve for blower.

The ratio falls between 1 and 1.25 for air-cock, axle-pivot, axle-pivot ring, brake-lever ratchet, connecting-rod liner, crank-strap, and double trees.

The ratio falls between 1.25 and 1.5 for axle-saddle, brake, brake-ratchet, brake-shaft, box-cap, rock-shaft, and double-seat valve.

The ratio falls between 1.5 and 2 for cylinder-head (front), cylinder, cross-head key, cross-head bracket, connecting-rod body, connecting-rod crank-box, brake-lever, brake-reach rod, ash-door, and axle-cap. The relative price of boring cylinder is 1.8 to 1 in the two sizes.

The ratio falls between 2 and 3 for axle front, ash-door housing, rear axle, bracket legs for skid engine, cap for shaft-bearing, check-valves, crank and crank-pin, cross-head, cylinder-head (back), cylinder-head guide-cap, and eccentric.

The ratio is above 3 for band-wheel and cylinder lagging.

These figures generally bear out our conclusion from the study of stationary engine manufacture, namely, that as the size of engine increases the weight element of cost increases more rapidly than the work (machining) element of cost. Improved economy is to be sought chiefly in a system of manufacturing component parts in quantities.

To any one familiar with this class of machinery the names above specified will convey a sufficiently clear idea of the shape and character of the prices.

FOUNDERY WORK.—The foundery of a large engine-works presents a very different appearance from that of a sewing-machine shop, although it may be remarked that in some cases the foundery absorbs similar relative proportions of the whole amount of labor employed in the respective establishments, and also that the average weight of metal cast per operative employed in the foundery may not differ greatly in the two cases. The small-parts foundery has an orderly appearance, with rows of small flasks arranged in symmetry, but the foundery devoted to heavy work presents as much a scene of confusion as a systematic process of manufacture can well exhibit.

In most engine-works loam and green sand molding are carried on in the same foundery. The cupolas are commonly placed on one side of the foundery, near the loam-molding end, and conveniently at hand are one or more heavy cranes, with a sweep enabling them to carry the molds formed upon the foundery floor to large drying ovens at the nearer side and end of the foundery. Sometimes overhead and traversing railways are used, but the ordinary dependence is upon large jib cranes, which, for the heaviest work, are operated by steam engines. The floor of this part of the foundery is not only diversified by piles of brick and sand, but is thickly set with temporary molds and furnaces of brick and clay, with flues extending from point to point of the uneven surface, and temporary brackets and sweep fixtures above them. The molding with flasks is done in the farther end of the foundery, and if there be shed or yard room in the vicinity, it will probably be found littered with an accumulation of disused flasks of various shapes and descriptions. In a small building near this end of the foundery, or in a loft above it, we will commonly find the pattern-store-room, with a stock of models of machine parts, prepared at great expense, and only a few of which can be employed at any one time. The rumblers, or tumbling barrels, for cleaning small castings, are usually set apart from the foundery in a partitioned inclosure, and the blower is placed on a platform among the foundery rafters, its draft-pipes extending to the several cupolas. The cupolas having their vents above the foundery floor are charged from above, outside the foundery. An incline leads to this part of the cupola, and up this incline the iron, flux, and fuel are wheeled or otherwise carried. Some of the larger founderies have hoists for this purpose and others have inclined railways operated by power. The sheds, with bins for the storage of coal, sand, fire-clay, and other supplies, are also necessary adjuncts of the foundery.

In a large engine- and boiler-works, the foundery floor usually constitutes between one-sixth and one-eighth of the total floor-space, and the number of square feet of floor-space per operative usually ranges between 64 and 100 square feet. In American shops the ordinary foundery for gray iron castings is a very conspicuous feature. In engine-building, a distinctive difference between American and English practice lies in the greater use of cast iron in America. This may be largely attributed to the excellence of American cast iron as compared with the English in the grades used for engine castings, the English Cleveland ore being liable to produce porous castings. Eccentric straps, brackets, and portions of the framing, made of wrought iron in England, are almost invariably made of cast iron here. In English steamers the bed-plates and condensers of the engines are frequently made of wrought-iron, but here the frames and the condensers (unless cylindrical) are made of cast iron. Of course there are some exceptions. The United States steamer Susquehanna was built in 1847 with wrought-iron engine frames, but the ordinary rule is cast iron. The tendency is to avoid blacksmithing, and if cast iron be unsuitable for an engine part, cast-steel or malleable iron, both of which are in growing favor, are often used in preference to wrought-iron forgings, especially if the piece be of a complex pattern. The forged parts of a frame are usually built up and bolted together, where a similar frame of cast iron would be made in one piece. In some cases the cylinders, frames, and bed-plates of small upright engines are cast in one piece, where they were formerly cast in three. All the coring, boring, reaming, counter-sinking, planing and turning for at least eight large bolts are thus dispensed with, and the construction is lighter and more steady.

In the handling and transformation of materials in the foundery, the proportions and economy of these materials, and the waste of metal in founding, first merit our consideration. The engine-foundery employs pig-iron as its raw material; but to go back a step, in casting iron pigs the ore weighs 1¼ to 3 times as much as the pig-iron produced, the limestone (flux) used ranging from one-twelfth to five-fourths of the weight of the pig, and the fuel from three-fourths to nine-fourths, usually about five-fourths of the weight of the pig. In casting iron pigs the reduction of weight from the ore to the pigs ranges from 20 to 75 per cent., and the further reduction of weight from the pigs to the formed casting may be amply estimated at 8 or 10 per cent. The wastage is greater than this for scrap and burnt iron. The loss of weight in melting is stated for new iron (pigs) to be 2 to 8 per cent. in stove founderies, and 4 to 10 per cent. in machinery and engine founderies, but for old plate- and sheet-iron the loss is from 20 to 30 per cent., and for burnt iron from 25 to as high as 60 per cent.

In the final casting of the machine parts the proportion of coal to iron is different and very much less than in casting pigs, the proportions being, coal 1 to iron from 7 to 9 in ordinary cases and depending upon the fluidity required in the iron.

In founding small machine parts the early part of the day and until about 3 o'clock in the afternoon is occupied in molding, and afterward the men take up the work of pouring the metal into the molds.

The power employed in a foundery is mainly used for blowing and rumbling. It averages in ordinary cases about four-fifths of a horse-power per operative (molders, core-makers, and laborers) in the foundery. As a rule the larger the capacity of the cupolas, the smaller is the relative amount of power required for the same metal flowed.

The output of a foundery by weight per operative varies greatly with the character of the work. It is in most cases fully as great for small green-sand castings as for heavy loam-castings, because the latter require so much more work of preparation and so many more laborers and helpers that the average daily flow per operative appears reduced. In a large foundery, with 96 operatives, having two 5-foot cupolas, 10,000 to 20,000 pounds per day were flowed. This, at an average of 15,000 pounds per day, would be 156 pounds per hand per day. Another engine- and boiler-shop has 200 men, about 35 of them in the foundery. There is one cupola with a maximum capacity of nearly 6 tons, but the average daily flow is 6,000 pounds. In other founderies, from observations and estimates, the weight of castings produced was found to range from 85 to 250 pounds per hand per day (molders, core-makers, and laborers). In one foundery of 36 men 4 tons per day are melted, an average of 222 pounds per man. As the cost of castings is usually rated by the pound, this is a very practical method of considering the matter. For small work we may establish a limit of output at which a foundery ceases to be a source of revenue. This also would serve to call attention to the importance of the value of time and to stimulate the employment of the best flasks and facilities. It is needless to say that it is in this as in other work—a diligent attention to these particulars makes all the difference between a paying and a profitless investment. In a foundery for small work, especially where hinged iron flasks are used, and in bench-molding in which machine-presses have effected a surprising saving of skill and time, a system may be mapped out by managers which may be easily followed and will give improved results, but in loam-molding no such uniformity nor mechanical routine is possible. In this, efficiency depends upon the skill and ingenuity of the molder, and the imaginative power required in getting out a complex casting with its molds and fixtures must be exercised to be appreciated. The loam-molder, like the engineer- and machine-designer, must be highly imaginative and cannot prosecute the highest arts of his craft without the possession of mental faculties of a kind in which persons with the most liberal collegiate education are often deficient.

Small castings are made in molds of green or damp sand held in flasks. The flasks are usually wooden boxes with ears or lugs and pin-holes by which they may be held together. In forming the mold several flasks may be mounted one upon another. An upper flask is called a cope, a lower flask a drag, a flask to draw out sidewise a cheek. A wood pattern is employed of a shape similar in most respects to the proposed casting, but a little larger to allow for the shrinkage of the metal in cooling, which is about one one-hundredth, or one-eighth of an inch to the foot. The pattern is divided into as many parts as may be necessary in order to take it out of the mold (after the sand has been formed about it) by the temporary removal of the cope or one of the cheeks. The lowest part is set into a drag in which its shape is formed in the sand. The upper part or parts are properly placed upon it surrounded by flasks which are filled with sand to make the impression of these parts. A coating of parting sand prevents the green sand in adjoining flasks from sticking together, so that each flask may be handled separately. They may, therefore, be taken apart, and the pieces of the pattern may be lifted out or removed. Then, being replaced in position, a hollow of the form of the casting is left into which the metal is poured through holes formed in the mold, while other and partial vents permit the escape of gas from the molten liquid through the body of the mold. To form holes in the casting, cores are made which are set into the mold separately in core-prints. If these cores formed part of the pattern it could not be lifted out of the mold. The difference in form between the pattern and the casting is that where there is a hole in the latter there is in the former a little boss or projection which forms a print in the mold in which the core rests. The cores are commonly made of sand, flour, and molasses, and are baked hard in ovens. The work of the green-sand molder is to fill and ram down the sand in the flasks so as to make a good mold, with proper vents for the pouring in of the metal and the escape of gas. Upon the removal of the pattern the interior of the mold is carefully smoothed and finished by slicks (smoothing tools of various designs for finishing the surface of the mold), and is made ready for the pouring of the metal. For small pieces the flasks and molds may be prepared most conveniently upon raised benches, and this work is called bench-molding.

For large work and great variety of design the building and storing of wood flasks and patterns would involve great expense, and resort is had to loam molding. In green-sand molding a man of ordinary intelligence may learn to do a certain class of "straight work", especially if assisted by hand-presses, in a very short time, although the full knowledge of the craft requires a long apprenticeship, but loam molding presents greater difficulties. The molder has first to build and fashion the mold to form the under side of the casting. Upon this he has to build the pattern, and upon this an upper mold. These constructions are of brick and clay mortar for the molds, and of clay and wood for the patterns. The lower mold being built upon a bottom plate and the upper mold upon an annular or encircling cope-plate, and the clay surfaces being prevented from sticking together by black washes or other parting facings, the molds may be taken apart and the pattern removed leaving a space to be occupied by the molten metal. The sustaining plates are of iron. Surfaces of revolution are formed in the clay by sweeps of the reverse form revolving upon temporary spindles. Cores and partial patterns of wood are used in building up the pattern, as some of its surfaces cannot well be formed without. In the molds the clay is sustained by the brickwork and by pieces of iron called "gaggers" inserted in the joints of the brickwork. The gas-vents are formed by molding ropes of straw into the clay and brickwork of the mold. Sometimes it is necessary to support or steady the cores or upper molds by inserting bits of tin or iron which can not be removed and are cast into the work. These are called chaplets. After each portion of the mold is put on, its surface is partly dried by burning charcoal held in braziers of wire, or by removing the part of the mold and placing it in an oven. Provision has to be made for lifting the several parts. The bottom plate is provided with lugs over which links are passed, and these are sustained by cross-bars or crosses which are lifted by cranes. The upper surfaces of the bars are toothed or notched to prevent the links from slipping, and levels are adjusted by means of intermediate hooks with turnbuckles for screwing up. If there be a cope-plate above and around the bottom plate, it may be lifted in a similar manner, but a portion of the mold which rests over the pattern has to be provided with a pricker-plate for lifting. Such a plate has rings on top and straight and diagonal teeth below, so that the adhesion of the clay, which is partly dried by a brazier, will lift the mass below it. Pricker-plates are built into the mold. Before casting, the mold must be baked thoroughly. If possible it is lifted and transferred to an oven, and in some founderies molds of large size are built upon rolling platforms so that they may be wheeled into the oven. But the largest molds have furnaces of brick and sheet-iron erected about them with a proper aperture for the chimney. The temporary furnaces built in the floor are often large enough to contain several hundred pounds of coal. They are of simple construction, a fire-box, a grate, and an ash-pit under it, and an opening on one side of the masonry covered by iron plates which are set in to form the fire-doors. Pipes convey the products of combustion to the casing of the mold, and provision is made for the access of the hot gases to every part of the mold. For a large mold the firing is continued several days. The mold is then examined for cracks and defects, which are puttied up. It is re-set, the top plate is put on and clamped to the bottom plate, the whole mold is surrounded by a boiler-plate inclosure rammed full with sand, and the mold is ready for the pouring in of the metal, iron pipes being placed in the sand to lead the gases from the straw-rope vents to the surface.

The foregoing is a scantling of the principal processes of founding, which will be readily understood. It is almost needless to say that in the actual work many contingencies have to be met and many precautions observed which are not here touched upon. For a 4-bladed propeller there are four side or cheek molds; the hub is formed in clay, but the blade-molds are formed to a wooden pattern, one pattern being used four times. Where ribs and hubs occur upon a surface of revolution the surface is formed by sweeps and the ribs and hubs are pieces of varnished wood set in. In molding large gears machines are sometimes used for making and spacing the forms of the teeth in the mold.

Loam-molding requires a coarser sand than green-sand molding, and instead of being merely damp the sand is reduced to a mortar. Green-sand molds are often dried in ovens, especially upon delicate work, for which the molds would otherwise be too fragile to resist the flow of the metal.

Of the time required in the operations of loam-molding some idea may be gained from the following examples: For making the mold or core of a large horizontal engine frame, the casting weighing 9 tons, a week's labor was required. For a propeller of over 3 tons weight and 16 feet in diameter a molder and a helper were half a day in building up the mold under a single blade. We may imagine from this the amount of time and labor and the cost of failure in molding and casting a propeller of 24 tons weight, such as that of the Cunard steamer Gallia. The largest steam cylinder ever cast was that of the engine of the steamer Pilgrim, at the Morgan Iron works. This took 45 tons (net) of metal, which required three hours and twenty minutes to melt, but was only two and a half minutes in filling the mold, being partly flowed in from two tanks and partly poured in from large ladles operated by cranes.

In casting large work of irregular form the contraction of the casting by cooling is liable to leave portions of the metal strained, either causing the work to break in cooling or to become liable to break under service. To guard against this Mr. Norman Wiard recommends that such castings be reheated in a brick oven and cooled slowly while covered with slack lime.

If the uniformity of product warrants the expense, loam-castings may of course be made by aid of flasks and patterns with nearly the same facility as those in green sand. In some engine founderies flasks are used for castings of the largest size, facilitating the work and diminishing the requirement of skilled labor. Loam, dried or baked in an oven, makes firmer and better molds than green sand. While, therefore, in some founderies a cylinder of a certain size may be cast in green sand, in others this size would be cast in dried loam as the superior method. But the difference in practice would depend mainly upon the convenience of facilities and the frequency of reproduction of a given form.

The rapid growth in the use of malleable iron and steel castings has been mentioned and promises to go to greater lengths, especially in respect to steel castings. By heating small gray iron or ordinary castings to cherry red in a covering of red hematite iron ore, and, cooling slowly, they become annealed and give up part of their carbon to the ore making the casting tougher and from two to four times as strong. Steel castings are much used, especially for parts requiring to be tough and strong but of shapes involving trouble in forging, particularly such as cross-heads and rocker-arms. These pieces are commonly made by parties making a specialty of this work and are supplied to engine-builders. The difficulty in making thin steel castings is due to the avidity with which the steel takes up carbon, but in the Cowing method the mold is of ground quartz, glue and flour, faced with powdered silica, and the steel cannot take up carbon from the mold, castings having been made with as little as .0007 per cent. of carbon, and which will bend without annealing. In the Chester steel process castings are first made of Bessemer steel in green sand. At first they are brittle but are annealed very much like malleable iron. The use of the Chester castings is highly approved in many classes of engine-work. There are various other processes depending upon different materials of the molds, the castings being toughened by subsequent annealing.

BLACKSMITHING.—In ordinary stationary-engine building the tendency during the past decade has been to contract the relative scope of the blacksmithing in more ways than one. The greater employment of steel and malleable iron castings and cold-rolled pump and piston-rods is one reason for this, and the employment of more powerful machine tools is another, so that both foundery and machine-shop have encroached upon the former province of the smithy. The blacksmith-shop is a small department of the work in the manufacture of stationary engines, especially of small engines. One man does the blacksmith work upon average on from 20 to 30 horse-power (10 inches by 20 inches) engines per annum. The blacksmith-shop of a large southern engine-works has 8 fires and a total of 22 men, of whom 6 are colored men, these acting as laborers and strikers, and not being skilled hands.

The power employed in blacksmithing is used in operating trips and steam-hammers and varies greatly with the weight of the implements used, which in turn varies with the character of the work, but in no very definitely assignable ratio. In some cases about 2 horse-power per operative is employed. Hammers are of course the principal power tools employed in blacksmithing. For small work these are built in great variety, drops and trips and direct-acting steam-hammers with ingenious devices to attain two objects, the cushioning of the blow and the regulation of its force and rapidity. By the improvement in these facilities the efficiency of labor has been greatly increased, sometimes more than doubled within the past ten years, and the precision and accuracy of the work has also been improved. In some shops a great improvement has been made in forging shafts under the drop with dies. For this work steel dies are considered too expensive, but cast-iron dies, which are easily made, suffice to bring the work so true that much labor is saved in machining. The advantage of this method is very conspicuous in making certain large sizes of graduated shafting where it is estimated to involve an eightfold advantage in the saving of time and labor, part of this being in the forging, but the greater part in the machining, there being much less metal to be removed by the slow operation of the cutting tool. On the other hand, in some shops, it is stated that the powerful cutting tools now in use are so efficient that the work from the blacksmith-shop does not require to be, and is not, forged as close as formerly.

The most powerful steam hammers in the country are found at the large works at Pittsburgh, Bridgewater, and Nashua, which make a specialty of heavy forgings, notably of marine shafts. The heaviest single shaft ever made in this country was forged under a hammer weighing 8½ tons, with a 7-foot stroke. To the steam piston of this hammer a pressure of 60,000 pounds might also be applied to increase the force of the down-stroke.

In marine work forgings are a factor of the highest importance, and the work being large and difficult the operations are of great interest. The skill of labor required is of a different kind from that of the machine-shop. The machinist may map out the course which he wishes to pursue and test everything with deliberation, and in the machine-shop there is a large body of workmen of the same grade of skill. In forging large work there are a few men who are not only highly skilled but are invested with duties which require such mental qualities that many men would not be capable of fulfilling them. The master-hammer man on such work must not only act correctly and with a skilled perception of the conditions involved, but he must act quickly; high qualities of executive decision are involved which may not be apparent from a mere description of the processes.

The following descriptions of the work of forging heavy marine machinery are derived partly from observations, but largely from a series of very graphic and reliable descriptions which have appeared in the engineering journal, Mechanics. All heavy forgings are handled by means of porter bars. These are shafts or bars of a size in some sort corresponding with the magnitude of the work involved. The iron is welded to them, and the forgings are thus built out from them as a basis, and they afford a means of handling the work in every stage of its progress. The forging of blooms and slabs from the scrap is a process which need hardly be described in this connection. The scrap is piled evenly upon a thick board and set into a furnace, and, when it comes to a welding heat, the mass which adheres together and is still sustained by the cinder of the board is taken out by tongs, and by means of overhead railways is run to a hammer or squeezer and reduced by blows or pressure to a compact bloom or bar, weighing, perhaps, 10 or 12 per cent. less than the original scrap. Such blooms and slabs are the raw materials of which forgings are made.

Forgings of many tons' weight are handled by a body of men (with no power appliances except a crane and a hammer) in the only practicable way, namely, by balancing. The porter bar rests in the loop of an endless chain hanging from the pulley of a crane, which pulley is hung in a swivel so as to permit of easy movement. As the work is forged on, the bar is moved to preserve the equilibrium, and to the cool end is clamped a wheel with handles by which it is turned over as it rests in the chain and while it is in process of hammering. From six to a dozen laborers turn the wheel and shift the work in accordance with the sign motions of the hammerman.

The porter-bar for the great shafts of the steamer Pilgrim was itself a shaft 15 feet long and weighing 12½ tons, each shaft of the Pilgrim being 40 feet long and weighing 81,200 pounds, or about three and one-quarter times as much as the porter-bar. The first operation is the "breaking down" of the porter-bar, which is simply heating the end and hammering it to a flattened and bulging surface upon which blooms and slabs may be laid. The blooms weigh about 240 pounds, and in forging this shaft, from 2,500 to 4,000 pounds of blooms were put on at a heat, and three hours were required for heating the larger piles. The heating was effected in a reverberatory blast-furnace, and the crane was in such a position that the work could be swung from the furnace door to the crane and back with the greatest facility. Only the unfinished end of the forging being placed in the furnace, it was not required to be very large or deep, and the opening was closed temporarily with a filling of brick and mud, except a little opening for watching the heat. As the moment for taking out such work approaches drops of molten metal are seen starting from the glowing mass and running down into the furnace. This is commonly called gravy, and is waste. It is sometimes an object to have the pieces heated of nearly uniform bulk, as there is then less waste. This shaft was forged under the directions of Mr. Dorrity, of the Morgan Iron Works. The weight of blooms used was 118,000 pounds, and the weight of shaft being 81,200 pounds, the diminution of weight is seen to have been about 40 per cent. There were 185 tons of coal used, or about 3½ pounds coal to 1 pound of blooms. The work involved a total of 360 days labor in 34 actual days, showing an average of 10 or 11 men per day. The value of the shaft was $10,000, or about 12 cents per pound. The blooms were made of nails, horse-shoes, and boiler-clippings, small scrap being used in preference to large. At an average added weight of 3,000 pounds per heat there would have been about 27 welding heats. A 15-inch shaft 10 feet long required 5 reheats—3 for welding or building out, 1 for roughing, and 1 for finishing, cutting off, and trimming, these last operations often requiring two heats for this size of shaft. The heats were not nearly as long as for the greater shaft, which was about 26 inches in diameter. The shaft was out only four minutes for roughing. The hammer in roughing went over it once in one minute, and a second time more slowly in two minutes, and the fourth minute was spent in straightening and alignment. Calipers with long handles are used in gauging, and a wedge-shaped implement with a handle is used in cutting off. Collars for such shafts are sometimes shrunk on, when it may become desirable that they should be removed, and sometimes they are forged upon the shaft, in which case they are made separately in halves and are heated to welding and stuck on the shaft in proper positions.

The forgings described are straight shafts, and although the work is large it is comparatively simple. In making solid crank-shafts greater difficulties are involved, and the liability to failure and imperfect work is so great that built-up shafts are now commonly employed upon merchant vessels, although in the navy and in naval contract works the crank-shafts are forged solid. It its necessary to forge upon the shaft at right angles and near together two heavy masses of metal. These are usually forged as solid masses, and are then cut out by drilling and slotting in the machine-shop so as to remove the portion of the forging between the double-crank arms. As the cooling of the forging leaves a "skin," the cutting away of these portions is liable to cause the shaft to spring out of line. The element of risk is large, and the failures in forging such work are not infrequent. Built-up crank-shafts are constructed in various ways, but commonly by shrinking the cranks upon the shafts and pressing in the pin which is made a little larger in one crank-arm than in the other to avoid binding when forced in. Solid forged crank-shafts were the prevailing practice both in Europe and America within the last fifteen years. To be sure in the earliest history of steam navigation built-up shafts were used, but these were of cast iron and comparatively small. The practice of making built-up wrought-iron shafts first gained foothold in this country and afterward in England. In 1860, Mr. J. S. Wilson, engineer for Neafie & Levy, Philadelphia, placed a built-up shaft in the steamer Saxony, which still plies between Philadelphia and Boston.

The following is a brief account of the forging of a half crank for a 14½-inch built-up shaft. The porter-bar being broken down or flattened, the crop end (that which had been cut off from a previous forging) of a shaft was first welded on. Then twelve 5- by 5- by 30-inch 240-pound blooms were welded on leaving a plain square end 26 by 18 inches. The necessary width was got by adding a slab on one side and then one on the other. Slabs being larger than blooms there is less waste in heating them. The end was worked to 42 by 14 inches when the finishing heat was taken and the crank was brought nearly to size, but somewhat wider and thicker and not necked. It was then ready for the machining. The crank was forged with counterweight, as is usual for all screw-shafts, but not for long-stroke paddle-wheel shafts.

In forging beam-straps smaller blooms are used. The most difficult, as well as one of the largest of marine forgings, is the rudder-frame. A large rudder-frame is made in eight pieces, which are afterward welded together. The largest of these is the main post, which is built out as usual from a porter-bar, with enlarged blocks for cutting out spaces for the pintles, and with offsets for the cross pieces. The back part of the frame is forged upon porter-bars to templates of wood in two pieces, and the inclined offsets coming from the main post to join them are set out by punching and cutting out a piece of the main post and throwing out the offsets by means of a taper punch, all being afterward forged and brought to a proper size. The tiller and two cross pieces are welded into scarfs of the curved back member as the work proceeds, and there then remain five welds to be made. The post is now machined, shaping the ends of the offsets and the bearings, and drilling and slotting out the spaces for the pintles. The frame is clamped together and laid on blocks, the ends to be welded being shaped into blunt wedges. The bearings are used in turning the frame upon the blocks. The welds are made by aid of a portable blast-forge and an anvil, two wedge-shaped filling pieces being welded in at each joint. The filling wedges are of sharper angles than the spaces to be filled, in order to make a sound joint in the middle. Ordinary frame parts are sometimes pieced merely by making a single V-joint, heating and hammering together.

The breakage of crank-shafts is an accident of great frequency, and one which involves in peril the lives of passengers on ocean steamers. Breakages are due to impurities, oxide, or even blow-holes spread under the hammer. They may also be due to the unequal cooling of a shaft, the exterior skin being first cooled and this preventing the interior body of metal from shrinking when it cools, so that it is less dense than the outer skin and may even be torn apart by its own efforts to contract. Breakage is also attributed to the attempt to forge large shafts under hammers which are not heavy enough for the work. The precautions which may be taken are then the careful selection and working of materials, the use of heavy hammers, the slow cooling of the shaft in slaked lime or ovens, and the forging of shafts hollow. So far as danger results from the attempt to forge very large shafts, it may be remarked that by running engines at higher speed with smaller diameter of propellers, so large shafts would not be required.

Steel shafts are also made. The largest steel shaft ever forged in this country was 28.6 feet long and 13 inches in diameter, and weighed 10,990 pounds after being lathe-turned. It was forged by the Nashua Iron and Steel Company, and shipped to Pittsburgh, Pennsylvania, for Gray's steamer line.

The cost of engine forgings varies from 7½ to 15 cents, small forgings usually costing least by the pound. Solid crank-shafts of large size cost more than ordinary forgings. Their cost is stated to range from 30 to 8 cents per pound, according to size. An estimate of the cost of a large solid crank-shaft is as follows, by the pound:

	Cents.
Material and forging (mostly labor)	16
Machining	9
Total	25

The frequency of failure enhances the cost, and built-up shafts may not cost half as much by the pound as solid forged shafts. At the United States navy-yard, Washington, the following labor was employed in forging a large shaft: One hammerman at $5 a day, 1 hammer-tender at $1 50 a day, 6 or 8 laborers at an average of $1 25 a day. Some private concerns pay their hammermen very much more than the rate stated ($5), especially on work requiring great skill, and the failure of which would result in thousands of dollars loss.

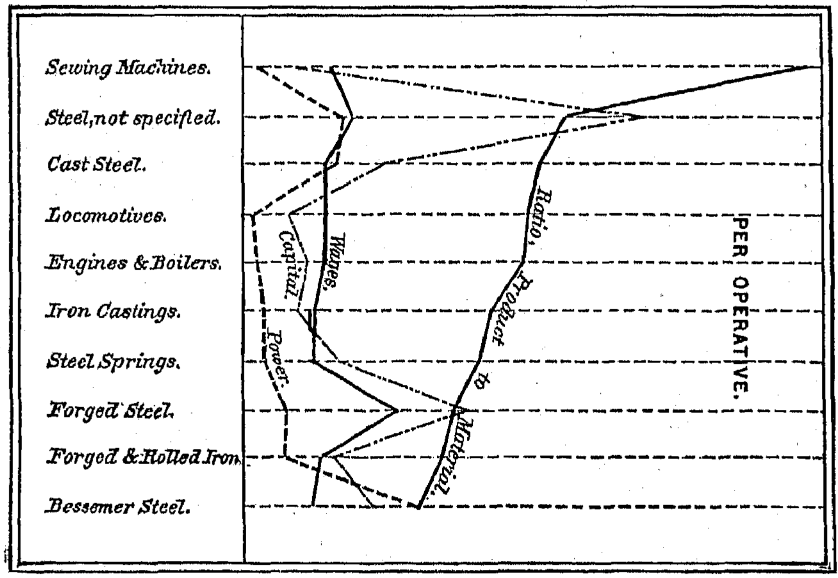


FIG. 1.—INDUSTRIAL CONDITIONS IN SEVERAL CLASSES OF MANUFACTURE OF METAL WORK.

Second item—Steel not otherwise specified.
The "per operative" rating is for wages, capital, and power.

MACHINE-PLANTS AND POWER.—The following are examples of the powers and machine-plants of engine-building shops. In one shop there are 62 men to 75 power machines, and the average length of shafting per operative is 6 feet of main and 8 feet of counter-shaft. In another engine-shop, 60 horse-power suffices to drive 80 machine-tools. The power per operative in engine-building shops usually ranges from one-half to three-fourths of a horse-power, and per ton of machine product per year about 6 or 8 horse-power are required. The power required in machining is relatively small, especially for light machinery. A small diagram is here introduced (Fig. 1) showing, per operative, the *relative* power, wages, capital, and ratio of value of product to material for some of the most important classes of metal manufacture, as returned in 1870.

A shop making about 2,500 horse-power of engines and boilers in a year, average size of engines built about 30 horse-power, has the following machine-plant:

32 lathes.
11 planers.
7 drill-presses.
1 vertical pulley-lathe, 12-foot swing.
1 bolt-cutter.
1 centering-machine.
1 slotting-machine.
2 pipe-cutting machines.
1 horizontal boring- and facing-machine.
1 vertical boring- and facing-machine.
1 milling-machine.
3 emery-stands.
370-feet line or main shaft.
450-feet counter-shaft.

This gives an average of about 5 feet line and 6½ feet counter-shaft per power machine.

A shop with 200 operatives, devoted almost exclusively to engine-building, has, for driving power, a "40-horse" engine, with the following power machines:

2 vertical facing and boring mills (Niles),
2 shapers (Bement),
1 slotter (Bement),
2 boring mills (Bement),
2 lathes (Chicopee),
6 lathes (Fitchburg),
5 planers,
2 pony-planers,
2 bolt-machines,

beside emery-wheel stands, drill-presses, grindstones, and punches. This machinery is extra heavy and solid for its work.

In another large shop, devoted to engine-building and mill-work, there is an 80-horse power engine, driving 101 iron- and 13 wood-working machines, the iron-working machinery being as follows and being operated by 112 men:

32 lathes, large, small, and boring.
13 planers.
4 pony-planers.
1 vertical boring and facing mill.
2 vertical slotters.
2 gear-cutters.
1 horizontel boring-mill.
4 bolt-cutters.
11 drill-presses.
5 milling-machines.
13 emery-stands.
13 grindstones.

In another large shop, almost exclusively devoted to boiler- and engine-work, a 35-horse power engine drives the following machine-shop tools:

3 large lathes,
6 medium and small lathes,
2 boring-lathes,
2 large power-planers,
2 medium power-planers,
1 pony-planer,
1 vertical boring-mill,
2 bolt-cutters,
1 vertical slotter,
2 milling-machines,

beside drill-presses, emery-stands, and grindstones.

These will serve as examples of practice. No very exact comparison is possible, because tools are not in continuous use, and in different shops different methods are applied to effect similar results.

In one instance it was found that for 468 machine-shop tools, many not in continuous use, there were used $228 worth of lubricating-oil and $1,620 worth of oil for machine cuts in a year.

SYSTEM OF MANUFACTURE.

Floor space.—In a large engine-works the total amount of floor space was found to be distributed approximately as follows, the percentages of the whole number of hands employed in the several shops and departments being also stated:

	Per cent. men.	Per cent. space.
Machine-shops	34	30
Foundery and cupolas	24	14
Boiler- and sheet-iron shops	24	22
Blacksmith-shop	10	7
Pattern- and wood-shops	4	3
Office, warehouse, and store-rooms	4	24

For the latter, more particularly, 30 per cent. machine-shops, 13 per cent. boiler-shop, 12 per cent. foundery, 9 per cent. cupolas, ovens and storehouses, 9 per cent. sheet-iron shop, 7 per cent. blacksmith-shop, 6 per cent. pattern store-room, 5 per cent. boiler- and engine-rooms, 4 per cent. offices, 3 per cent. pattern-shop, 1 per cent. sand-shed, 1 per cent. tool-room.

There thus appears to be in floor space per man, about 130 square feet in machine-shops, 85 square feet in foundery, 140 square feet in boiler-shops, and 100 square feet in blacksmith-shops. Of course every shop will vary in these respects, some having much more foundery space per operative.

Progress of uniform methods.—In the manufacture of small mechanism prolific output with great excellence of work has been realized through study and analysis. In the manufacture of heavier mechanism the same analytic appreciation is at work. It has a harder and a greater problem, but its demonstration is merely a matter of time. Machine design is yet in its infancy, and so soon as there shall be a pause in innovation and improvement establishing more firmly the settled functions of machinery, then the time will be ripe for harmonizing the components of heavy machinery so as to effect a great industrial saving. The existing patterns of steam-engines differing in no very essential details are of a number and variety which I will not attempt to estimate. Some present special points of merit, and none perhaps are so poor as not to possess at least special points of advertisement. And some features which are highly meritorious under certain conditions of use become defects under other conditions. Were engines built singly by old and unimproved methods an indefinite number of designs might continue to be used, but in the competition of more productive and uniform methods it follows that in the course of time, and upon the expiration of patents for special features, a limited number of designs will prevail, viz, those which are most adaptable to the needs of large classes of steam users, and which are cheapest to build for good and efficient service.

Old machine-shop methods are in process of change, and the improvements are usually less suitable to the requirements of small makers and for single pieces of mechanism than to the wholesale fabrication of uniform work. Already methods which suggest those of the watch factory are in use at some of our large engine-shops, and engines of considerable size are built in lots of 10 with the employment of standard gauges and templates. Workmen are employed to repeat a given operation upon great numbers of parts, and where this can not be done the work is classified by its likeness, and one workman is kept upon one class of work. For example, let us consider the work of planing. There are in a room, say, 20 or 30 planers operating upon a much greater number of different parts of machines. If the manager or foreman be unable to keep one planer running at one speed on one class of work and under one man, he exerts his ingenuity to come as near this desideratum as possible. The better he is able to succeed in such matters the more exact is the workmanship and the more profitable the manufacture. Further than this, the machinery so made, other things being equal, commends itself to a greater number of purchasers, and under enterprising oversight the large demand reacts to insure better facilities for uniform work.

The attempt to gain valuable time by systematizing work is an attempt to diminish the time, not of actual machine tooling, but of setting, waiting, and preparation; and an inquiry into the actual time of machine operations reveals the great amount and importance of the portion of time not occupied by the actual tooling. In machining gun components we may easily estimate by number of parts turned out in a day, and such estimates are made the basis of wages; but in the large work of machine-shops there must be a large and ill-defined allowance of time for setting and waiting. Making an estimate of time spent in actual machine tooling upon work, we find that it must be doubled, trebled, or quadrupled in many cases, in order to account for the total time. Herein lies the value of handy tools in which American shops excel, and of which many examples might be cited. I will mention one. Messrs. William Sellers & Co. build a lathe in which the screw and hand-wheel motions are displaced by a device which does the setting by a single motion of the hand. Such a device may at first sight seem trivial and of no great advantage, but when we estimate the number of times in a day a machinist has to perform this motion, and the aggregate saving of time, we find that upon some classes of work it has a money value which is not to be despised. Such handy appliances also help the spirit of the workman, and stimulate him to alacrity in the performance of his work.

In time of setting and waiting, also, lies the great difference in cost between large work, or work which can be done piece after piece of the same kind, keeping one workman on one job, and work which involves a new essay of preparation, adjustment, and experiment for every successive piece. Thus in making pulleys of one size in large lots, and in making various parts of engines in small lots, there is a vast difference in cost of work by the pound. The value and productive power of labor can best be maintained by close attention to shop system, and a convenient tool, kept in good working order, may involve as great a saving as a rapid-acting tool.

Interchangeability in machine-work.—Interchangeability in machine work has made as much progress as may be expected under conditions of change. It involves stability, and stability, while desirable in itself, is a bar to further progressive development. It is a practice like the freezing of water, tending to prevent further flow. That it already exercises such an influence may be noted in some instances. The introduction of metric measures meets its most serious opposition in the existence of standard tools and gauges whose proportions are only commensurate with the inch system. So, too, improvements in certain classes of machinery have to be very deserving to gain a foothold where existing standards would be disturbed by them.

In machines, interchangeability demands the best patterns as a guarantee against changes which would impair its value. For a single piece of mechanism it might not be worth while to enter into so close a study of the proportionment of the several parts singly or relatively as to secure absolutely the best results, but when the machine is designed to be duplicated by thousands and for an indefinite period of time, it is expedient to have a design well worth maintaining.

Some degree of interchangeability prevails in the transmissive machinery of factories. The shafting, pulleys, and hangers in a mill, as has been well pointed out, constitute a great machine, generally much greater and more expensive than any single machine employed, and not only so, but a machine which is used in every class of manufacture and may properly have many of its parts and fittings interchangeably duplicated in all.

A highly important move was made in furthering uniformity in general machine-work by the adoption of an American standard screw-thread. This standard, with standard bolt-heads and nuts, was proposed by Mr. William Sellers, and adopted by the Franklin Institute December 15, 1864, and by the United States Navy in 1868, and it is now the acknowledged standard of American practice, so well known and approved that it may be regarded as part of the groundwork upon which future developments in interchangeability will rest.

"Inch-divided lead screws", says Mr. Coleman Sellers, "are common to all lathes in all parts of the world". The crystallization of practice in the uniformity of shop sizes, based upon the inch, forms a growing obstacle to the introduction of metric units. Whether or not these units are desirable in their application to machine-work, almost the whole weight of American practice seems against them. This practice has unquestionably led in many advances above old-world methods, and the same judgment of the fitness of things which has stimulated departures from former practice by American machinists seems to incline them to hold to their present convenient units and shop sizes rather than to sacrifice them for conformity with the less desirable systems of countries whose machinery is less uniform and no more accurate than theirs. As used, the beauty of the inch system is in its customary division into convenient aliquot parts, eighths, sixteenths, and sixty-fourths, nor is the decimal system, where it appears convenient, necessarily sacrificed. A 10-foot pole is a convenient implement, but a 10-meter pole could not be handled readily, so that in any case convenience would require that the metric system should be broken by non-metric divisions. In like manner a thousandth of an inch is a recognized standard in fine gauging and jeweler's work. A draughtsman desiring to make a drawing to a reduced scale would naturally and easily make it one-half, one-fourth, or one-eighth full size, but if he did so with metric measures his dimensions would often come in decimals of three or four places, and to make his drawing one-tenth or one-fifth scale would be decidedly troublesome. In short, the handy units and convenient multiples and divisors which the so-called inch system has are lacking in the metric system. Machinery involves proportions as well as mere aggregate measures. The metric system, though competent to register such measures, cannot be made to express with convenience these natural and useful proportions unless indeed new divisions be introduced, making it also like the inch system, a mixed system.

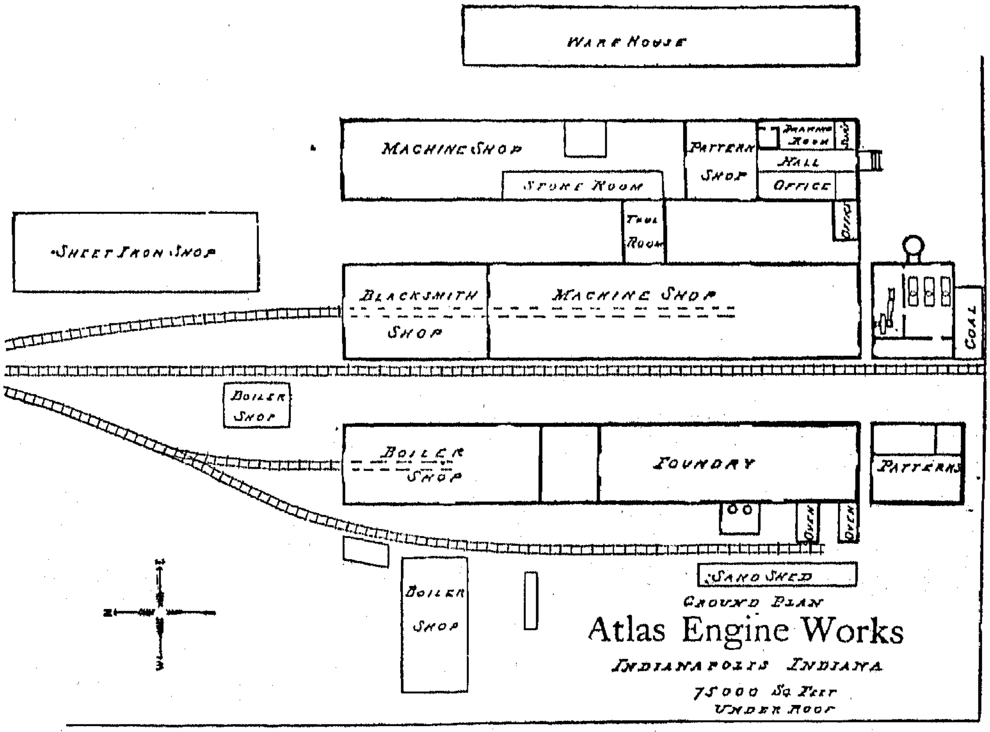


Fig. 2.—Plan of Engine Works.

Interchangeable gearing has forms of teeth by which wheels of any size, from one having the smallest practicable number of teeth up to a rack, and having the same pitch, may be made to work truly together. Some time since, Mr. F. A. Pratt, of the Pratt and Whitney Company, Hartford, Connecticut, observing that gear-wheels were the only important element in machinists' work which had not been reduced to a satisfactory system for making interchangeable parts, applied his attention to devising such a system for cutting gears. This interchangeable system is founded upon a carefully studied series of templates and cutters for a series of diametral pitches covering all ordinary requirements with sensible accuracy. Uniformity is maintained by finishing the cutters by means of templates in a pantagraphic milling- or edging-machine, the templates being formed in an epicycloidal milling-machine, in which the motion of the cutting-mill is guided by means of wrapping connections upon surfaces representing pitch and describing circles, the whole system and its appliances being the result of ingenuity and careful study, while it may be considered a noteworthy step in the advancement of interchangeability in mechanism. The diametral pitches and other involved dimensions are the usual inch and fractional dimensions.

Arrangement of shops.—The Atlas engine-works of Indianapolis, Indiana, is one of the best systematized establishments of its kind in the country, and the plan of the works here presented shows a carefully studied arrangement. The works are located in the open country, with unlimited room, and nothing to prevent a good arrangement of shops. They are also exclusively devoted to the manufacture of engines and boilers, not including, as is often the case, the manufacture of milling and general machinery. The plan will explain itself, but we may specially note the arrangement of tracks on which a small locomotive is employed for moving work and bringing in materials. Except the small house for the storage of patterns, which is in two stories, the works are entirely upon the ground floor, while in some shops in crowded quarters in cities, the buildings have three or four stories.

In founderies and machine-shops, jib-cranes are in most common use, and we will sometimes find such a crane near each of the largest pieces of machinery, but more usually a few large cranes sweeping over extensive areas. Traveling cranes are not as commonly in use, but permitting, as they do, the utmost freedom in moving from any part to any other part of a shop, they are to be commended for increasing facility of work. They are used in some large works, for example, in the machine-shop of the Morgan iron-works. In Fig. 3 is shown a power-traveling crane. This is of a type built by the Yale Manufacturing Company, Stamford, Connecticut, with improved devices for traversing the bridge on the tracks and the trolley on the bridge. These cranes are used by the Harris Corliss works, Providence, Rhode Island; the Chicago foundery company, Erie City iron-works, and other establishments. The highest capacity as yet built is twenty tons, and the greatest span of bridge is 71 feet.

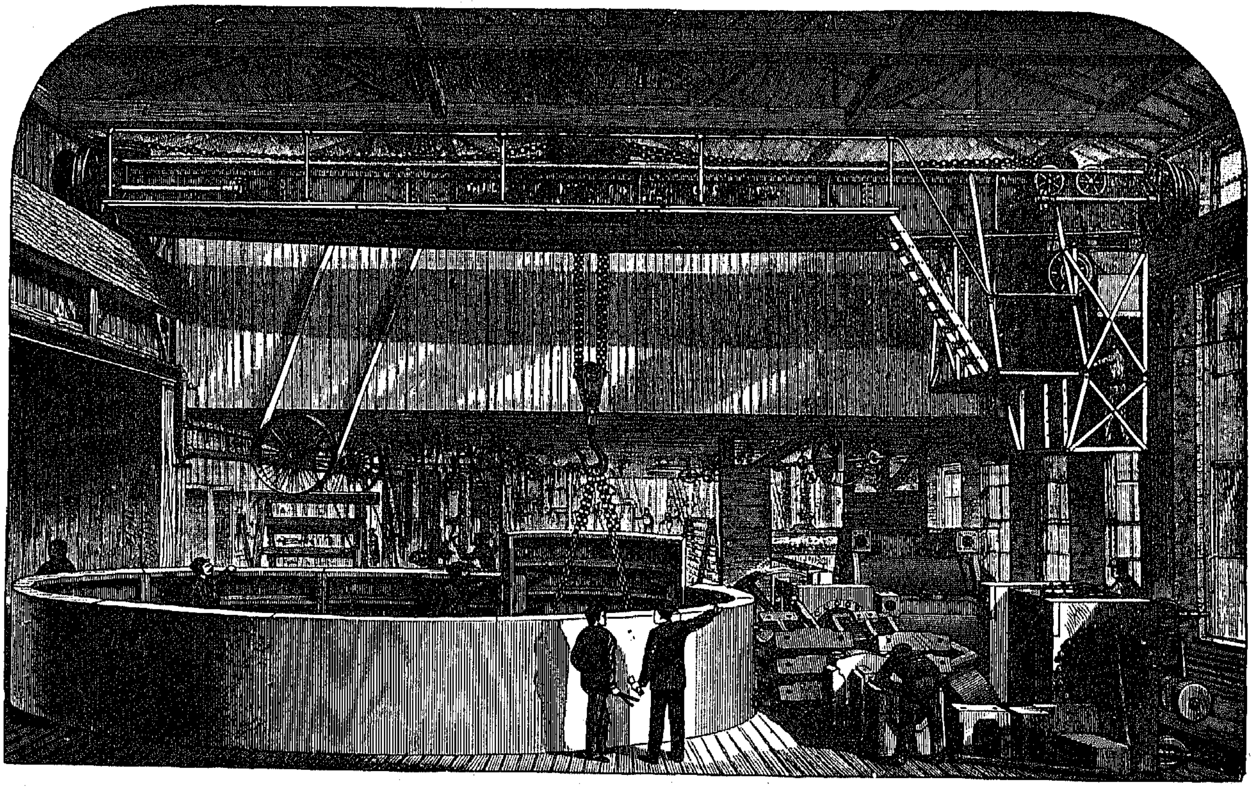


FIG. 3.—POWER TRAVELING CRANE.

In Fig. 4 is shown a jib crane in a foundery. The outer end of the jib has a truck with wheels moving on a circular track. This dispenses with the ordinary strut, and the jib beams, being supported at both ends, permit a larger space to be reached for the same load and strength of beams than with the ordinary jib. These appliances appear to comprehend a large shop in one machine. Their convenience is manifest, and their employment rapidly increasing, registers a notable industrial advance.

Overhead railways or transfer tracks are used in forge-shops, boiler-shops, and other places where the work has always to be moved in one path, and their utility in establishments of systematic arrangement is sufficiently obvious.

At the works of the Hartford engineering company, manufacturers of Buckeye engines, the arrangements for handling heavy parts deserve mention. In a central yard there is a very large (25-ton) steam-crane, with a jib 53 feet long. This is surrounded by one-story shops, over portions of which the crane sweeps. In the roofs and ceilings of these shops are five large trap-doors, one over the heavy lathes, one over the planing and slotting machines, two over boring-mills, and one over the erecting-shop. Thus engine parts weighing fifteen tons or more may be turned, passed to the machinery for planing and slotting, and thence to the boring-mills, and finally placed in position for erecting or assembling the parts together, all by the sweep of a single crane in the fraction of a circle. Auxiliary to this arrangement are a number of traveling cranes with trolleys, in sections of the shop reached by the large jib-crane. These traveling cranes serve to convey work to tools beyond the trap-doors, and are required only in portions of the shop.

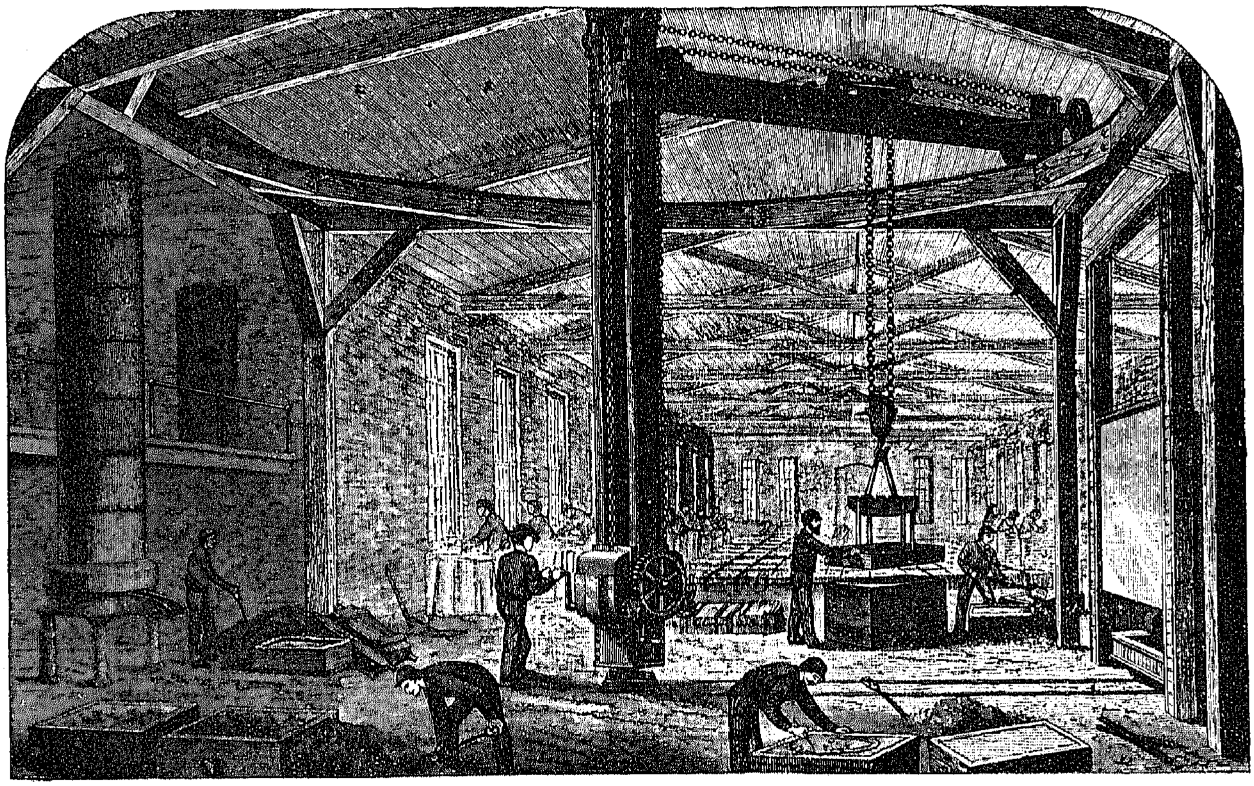


FIG. 4.—HAND TRAVELING CRANE.

Handling tools and drawings.—As an example of the methods pursued at the Atlas Engine works, the system of handling tools and drawings may be cited. It is in many respects similar to that in use at the Baldwin Locomotive works. Such system, although its details may seem simple, is a feature of no mean importance and one too much neglected in many shops. It saves time, worry, and confusion, and prevents misunderstanding and loss. In watch manufacture on a large scale it is often hard to draw the line where book-keeping ends and machine-work begins, and the details, specified as follows, are a proper part of the machinery of management in engine works:

Tools are taken out by checks. Each machinist has six checks, and when he takes out a tool the check is placed in the case from which the tool is taken. In reference to drawings, the originals are kept in a large office-vault, and for shop use tracing-cloth copies are provided, fastened on boards and shellaced. The shop copies are kept in racks, and when a drawing is given out to a machinist, the tool-room keeper pulls down a vertical slide-plate like Fig. 5, with pins on which are hung numbered lists of the drawings in each rack. One of these lists is shown in Fig. 6. They are backed with board, and the machinist's check is hung upon a pin opposite the number of the drawing taken out. The attendant then slides the plate up out of sight and the record cannot easily be disturbed. This may seem a very simple provision, but as a single slide-plate may furnish a complete index and account for between 500 and 600 drawings, it is really a labor-saving provision which has a real money value.

In the like details of many other machine-shops, efficient systems prevail. In the shops of the Hartford Engineering company all drawings are made upon sheets of two or three uniform sizes. These are traced for office file, and blue prints for shop use are taking from the tracings and mounted on boards. The consequence is that a drawing may be referred to as easily as one would turn to the page of a book, and the whole record of machine details for a wide range of work is comprised in the contents of a very small chest of partitioned drawers. Without this system, or with the old lack of system, most draughtsmen know how much space is occupied by drawings of different sizes and descriptions, unclassified odds and ends worn and tattered by continual turning to find some detail secreted under the heap. Many of these mechanical drawings involve a cost of labor no less than would be required by meritorious oil paintings of equal surface, and their proper handling is is enough to mark the difference between good work and poor work, or between profit and loss.

Assembling.—The fitting and setting up of large engines is not usually done in such a uniform and continuous manner as to admit of exact estimates of the time and labor required, but it is found that 10 men will erect 14 10 horse-power horizontal portable engines and boilers in a week of sixty hours. In this case the demand for the product was so great that the machinery was being built and set up continuously week after week. The time of course did not include any part of the boiler making, but only the assembling of the boiler with engine and framing parts.

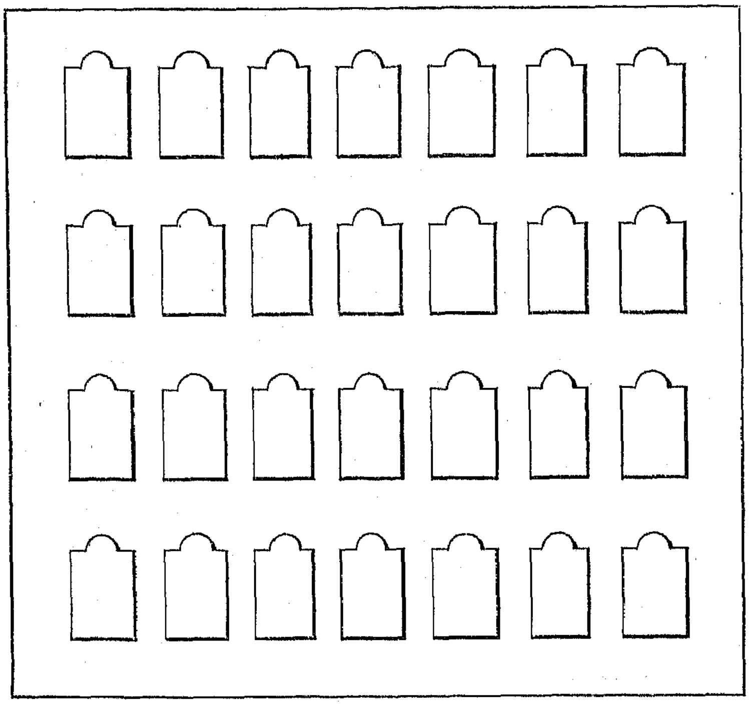


FIG. 5.—DETAILS OF SYSTEM FOR CARE OF DRAWINGS.

Shrinkage may be properly considered in this connection. It is a method in frequent use. Cranks are shrunk upon crank-pins and shafts, straps are shrunk upon beam-centers, deadwood rings are shrunk upon marine shafts, collars are often shrunk upon shafts, rims upon wheels, strengthening-rings upon hubs and bosses, and so on.

In shrinking a 15½-inch crank-pin into marine cranks, less than one-sixty-fourth inch is allowed for shrinkage of the diameters. The method employed is as follows: The cranks are blocked up, edges upward, on a boiler-iron floor, laid over a 6-inch layer of loam, so that a fire may be built about them. They are brought to a red heat by a wood fire, built in a temporary casing of boiler plates. After the fire is removed and the holes are swabbed out, the cranks are laid faces up, the pins are set in, and the companion cranks, similarly heated, are laid over and surrounding the pins, being kept in proper place by parallel distance-blocks laid between the upper and lower cranks. All the work is trued from the faces of pins and cranks, and care must be exercised in blocking up the parts, so as to secure parallelism and correct centering

All the heating that deadwood rings require is simply obtained by standing them on end and kindling an open wood fire about them. These rings are of brass and rest in brass and lignum-vitæ in the deadwood of the steamship.

In shrinking, a slight allowance is made for contraction by making the hole a little smaller than the piece to be inserted would be if both parts were cool. Without this allowance the pieces will be loose, but a more common difficulty is due to giving too much allowance, in which case the eye contracts so powerfully upon its seat or shaft that it becomes cracked and strained near the seat, and thus losing its hold becomes loose as before, the grip of the eye being permanently destroyed. It is easy to heat and slide on a ring or strap which will certainly break apart in the contraction of cooling, and it usually requires less than one-eighth of an inch allowance to do this. Some examples of allowances for successful shrinkages are: One-sixty-fourth of an inch scant for a 16-inch pin or shaft, (another) one-one-hundred and twenty-eighth of an inch for a 16-inch pin or shaft, and three-one-hundred and twenty-eighths of an inch for a 26-inch shaft. Probably even smaller allowances would make good shrink-fits, while larger would be liable to injure the eye.

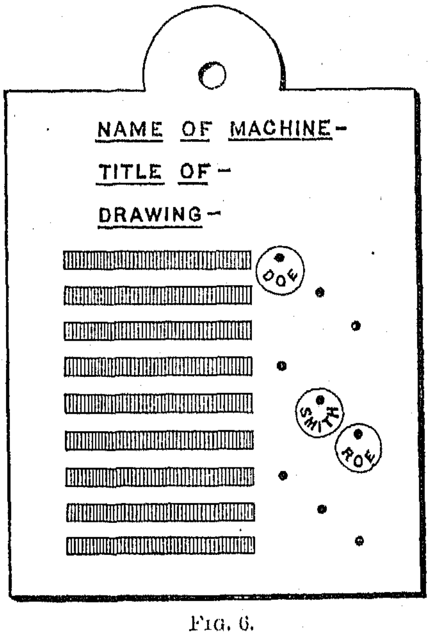


FIG. 6.

Planing.—Planing and drilling are the principal work on engine-frames. The time required in planing the frame of an 8- by 12-inch engine is ten hours, of a 16- by 30-inch engine of the same style twenty hours. Twelve hours were spent in planing the frame of a 10- by 20-inch slide-valve engine of another make. The surfaces are gone over twice, rough and finish, the latter with a three-eighth-inch feed. The Sellers planer, operating with 3 or 4 tools, actually does three times as quick work as an ordinary planer in planing upon the frames and cylinders of steam-pumps.

In planing the frame-feet of an 18- by 42-inch Corliss engine five hours were spent, these feet being given only one cut. Five hours also were required in planing the bottom of a 10- by 16-inch (cylinder) plain slide-valve engine-frame, a single cut being given.

Forty hours were required in rough and finish planing the frame of an 18- by 42-inch Corliss engine cylinder, this being done on a 54-inch planer.

In machining built-up cranks the keyways are first slotted, and wooden keys are used in them to assist in the subsequent work. The cranks are first planed to thickness. Then scribe-lines are punched in them and they go to the slotter, where the edges are finished to the desired profile. The slotting-tool is fed with water or soapsuds and takes a chip 1½ inches wide and one-quarter inch thick in machining a large crank.

Links are machined in various ways. For making small links, the Greenwood planer-chuck, with curve-cutting attachment, is a convenient tool. Special machines are sometimes used for making links. They may also be slotted to shape, or may be turned in a vertical mill, or planed to a pattern.

Ordinary rough and finish cuts in planing are made with round-nosed tools. The second-cut tool is wider than the first, and the angle between tool and surface is slightly smaller. The velocity is usually the same for both cuts, ordinarily 20 feet a minute, or 4 inches a second, but sometimes as slow as 13 feet a minute. A first cut on a Pratt & Whitney planer, with a "rooter" or round-nosed tool, was noted to be one-thirty-second inch deep, and the speed was 16 inches in 4 seconds. The ratchet had 28 teeth, with 4 revolutions per inch of screw, and 4 teeth were fed, giving a cross-feed of one-twenty-eighth of an inch. Other planing cuts noted in soft cast-iron, speed 33 inches in 6 seconds: rough cut, one-sixteenth inch deep, one-sixty-fourth to one-thirty-second inch feed; finish cut, one-thirty-second inch deep, one-thirty-second to three-sixty-fourths inch feed. In general, rough cuts run from one-sixty-fourth to one-eighth inch feed, according to tool and finish; finish cuts, one-sixty-fourth inch upward, sometimes with flat tools as much as 2½ inches. In work which requires any degree of finish two cuts are always necessary. It is considered that, with proper management, no work ought to require more than 3 cuts. The final surface-cut on a fine plate was made with a flat-nosed tool, 1 inch feed and one-one-hundredth inch depth of cut.

For planing short cuts shaping machines are useful, but the length of cut is limited by the firmness necessary for accurate work. Under 16 inches traverse tolerably accurate work may be done with an ordinary shaper.

Turning.—The manner of turning one of the great shafts of the "Pilgrim" was as follows: The shaft was drawn from the forge-room to the machine-shop by aid of a steam-winch, and it was then lifted and carried by an overhead traveler. It needed no straightening. The lathesman found centers and tested the centering by four lines drawn along the side of the shaft at the four sides. The centering was done by a half-inch drill followed by a flat countersink, the same angle as the centers (77°), and 2¼ inches in diameter at the largest end. The shaft, 40 feet long and weighing 81,200 pounds, was swung upon centers, without other support, while a narrow place in the middle was turned up to take a cast-iron bearing-block for the support of the weight during the 170 hours which the turning required. The lathe used had a head-spindle only 7 inches in diameter and a 5¾ inches tail-spindle. The crank-seat was turned three-one-hundred and twenty-eighths of an inch larger than the crank-eye for shrinkage.

There was not as much work in machining this shaft as upon a much smaller, solid forged crank-shaft of the following dimensions: length, 16 feet; diameter, 15 inches; center shaft to center crank-eye, 18 inches. This required 300 hours' work in machining, largely turning, but also drilling, slotting, cutting-out, and planing.

Forged weight, 11 tons; removed by machinery, 2 tons; finished weight, 9 tons. The cutting-out between the cranks removed much of the weight. The shaft was held between the centers without center-rest or steadiment. In built-up crank-shafts, after the cranks and pins have been shrunk on, it is customary to assure the truth of the shaft by a light finishing cut.

The following relates to the turning of a very large fly-wheel by Watts & Campbell, Newark, New Jersey. The wheel was built in 7 sections, and had a weight of 40 tons. Its diameter was 25 feet, its face, 7 feet 6 inches, with 3 crowns, on which three 24-inch belts were to run. In turning this wheel the lathe ran two weeks night and day, say, two hundred and eighty-eight hours. One revolution occupied nearly 6 minutes, and 5 tons of chips were removed from the surface.

In machining a large pulley fly-wheel 10 feet 4 inches in diameter and 30 inches face, sixty-four hours were required, the operations being the turning of the face (2 cuts), the facing off, and the boring out of the hub.

In the shops of William Sellers & Co., Philadelphia, pulleys are rapidly rough-turned by a lathe in which five tools work side by side. A special apparatus is necessary, in order to obtain uniformity of bearing and avoid discontinuous cuts of the several tools. The finish cut is made with a single tool going over the whole face of the pulley with a feed of from one-half to three-eighths of an inch. Of the speeds of turning tools, the following notes were taken in one shop:

	Material.	Per minute.	
		Revolutions.	Speed.
			Feet.
18-foot pulley	Cast iron	¼	14.13
18-inch pulley	....do	3½	16.48
8-inch shaft	Wrought iron...	8	16.75
2-inch shaft	....do	32	16.75
1-inch valve-rod	....do	64	16.75
¾-inch spindle	Steel.............	64	12.64

Drilling.—The work of drilling upon a Corliss engine-cylinder is full twice as much as upon a plain slide-valve engine-cylinder of the same size (as stated in a shop where both styles were built).

There is about five hours' work of drilling on each frame of a plain slide-valve engine between the sizes of engine which may be designated, from their cylinder dimensions, as 8 by 12-inch and 16 by 30-inch engines.

The speed of twist-drills is stated in velocity of periphery at 15 feet per minute for steel of usual temper, 20 feet per minute for wrought, malleable, and cast iron, and 25 feet per minute for brass and the softer metals. These speeds are based upon a soft temper of the metals as is usual. The use of belted drills permits higher speeds with less shock than the use of geared drills.

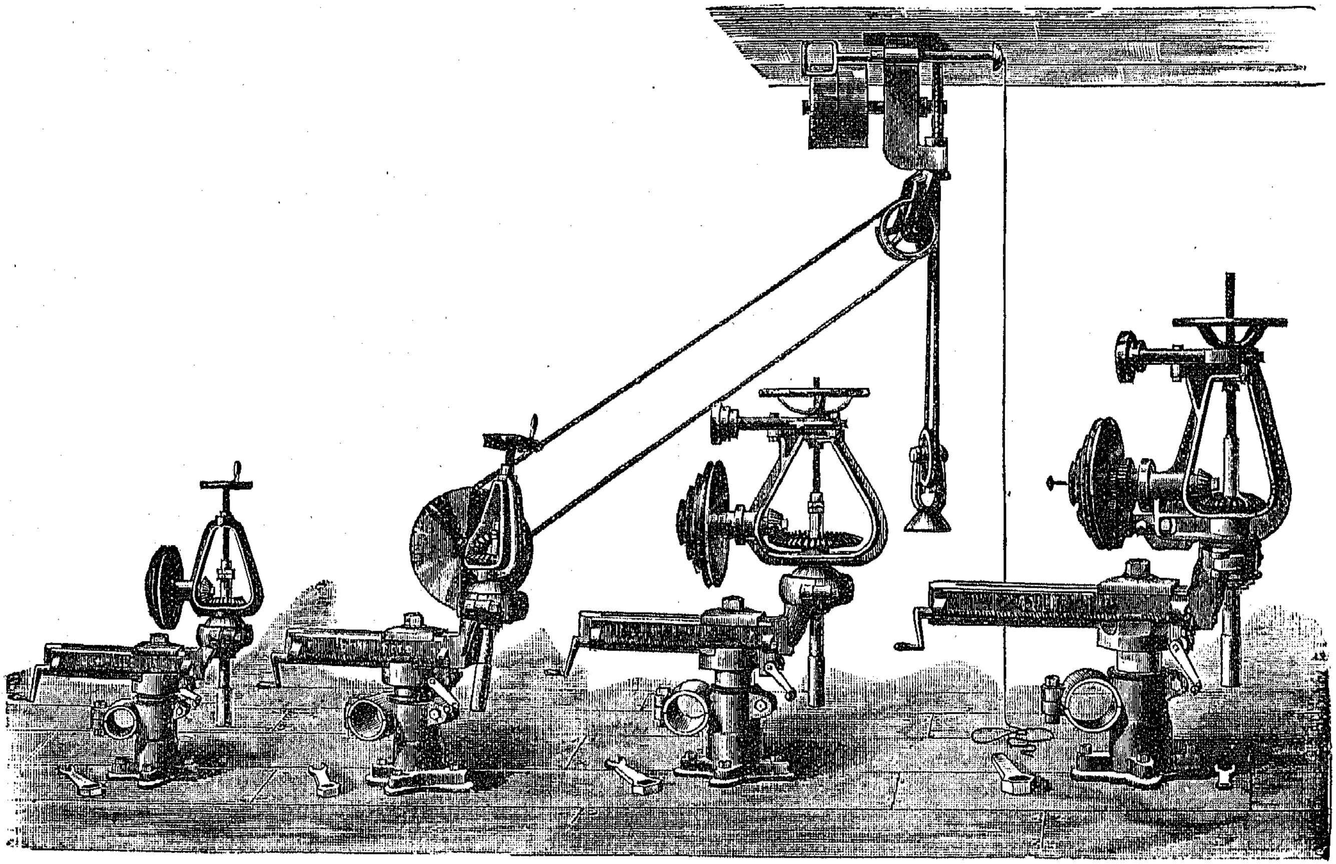


FIG. 7.—PORTABLE DRILLS.

The importance of having tools which are convenient to handle as well as rapid in action has been elsewhere dwelt upon. In engine-building, and especially in the erection of marine and other large engines, perhaps no tool is more handy or more generally used than the Thorne and De Haven portable drill. For castings of 200 pounds and over, and holes from three-eighths inch to 2½ inches, the portable is more convenient than a fixed drill. It is illustrated in Fig. 7, from which the drill is seen to be driven by a leather cord, so that it may be placed at any desirable distance from the countershaft, the surplus connection being taken up by a straining pulley and weight hanging in a bight of the cord. It is also mounted in a spherical joint, so that it may be inclined at any desired angle. On hurried work, one man with this drill does ten or twelve times as much work as a man with a ratchet-drill. At the Fulton Iron Works (Gerard B. Allen & Co.), Saint Louis, one man with one of these tools drilled in a circle of about 7 feet, with a 1½-inch drill, 22 holes 2 inches deep and 10 holes 3 inches deep in 5 hours. This was at a rate of about one-fourth of an inch a minute with 32 changes of work. The drill does a work equal to that of 12 men with ratchets, as men ordinarily work, or the work of at least 6 men working at their best.

Boring.—In boring an 18- by 42-inch Corliss engine-cylinder twenty-four hours are required for two cuts, the finish being slower than the rough cut. The finish feed is about one-eighth of an inch. We may note here, as remarked under the head of locomotive manufacture, that the Seller's machine bores cylinders, faces flanges, and counterbores cylinders equal to the largest locomotive size in three hours and a half, the usual time having previously been over thirteen hours here, and twenty to forty hours in foreign countries. The Wheelock apparatus for reboring cylinders, without removing the back cylinder-head, will rebore sizes of 8 to 24 inches in diameter in from eight to twelve hours.

The boring of a specified pair of large cranks is described as follows: After slotting the cranks to profile, they are put under a vertical boring-mill and the eye is bored for the crank-pin. A 4½-inch flat drill is first run through the cranks. This permits 4-inch boring-bars to be passed through them. The upper ends of these boring-bars are keyed in to the vertical spindle-socket and the lower ends run in collars in the bed-plate of the mill. The boring-tools are double-ended, and each end takes a cut an inch deep, with a slow feed. The tools are keyed into the boring-bar. By three through cuts the hole is bored from 4½ to near 15½ inches. The finish cut is made dry, the previous cuts having been made with soapsuds. The shaft-holes are bored in an entirely different manner. A slotted cross is used, with stave-shaped tools, which make an annular cut, and take out a solid core of metal. The finish boring of the shaft-seat is not made until after the crank-pin is shrunk in.

Machining small parts.—In this work milling machinery is sometimes used. The small parts being required in comparatively small quantities, are not produced with anything like the cheapness of small gun and sewing-machine parts. Keys, which, if made in large quantities, might be cheaply made, as made, are usually quite expensive, and other small parts, straps, link-blocks, liners, and the like, if manufactured as small hardware, in quantities, would cost, in some cases, no more than one-eighth of their cost by slow machine-shop methods. A small key, for example, is rated at $1 50, as made in the shop; that is to say, it costs ten times as much as a butt-plate or a lock-plate, and three times as much as a complete bayonet—parts of a gun as large, or larger, than the key, more elaborate in form, and requiring as much and as accurate machining. Such comparisons convey an idea of the advantages of uniformity of design and large manufacture, which is not without its lessons. A valve cross-head for a small engine consists of a cylindrical piece of steel bored through in two dimensions, there being a step in the bore, and on the side of the piece is a boss or hub, with a drilled hole. One man makes 20 of these in three days, spending one and a quarter hour on each. The work is done on a lathe, and consists of facing and rounding 3 ends, drilling 2 holes, and drilling and counterboring 2 holes for each piece.

In some cases highly economical results are obtained by finishing machine parts by grinding instead of filing. This is done upon the surface-grinding machine, which appears in some respects like a planer, the work being fastened upon a reciprocating bed and passing under an emery wheel which has a cross-feed and vertical adjustment and is driven by a drum at the back of the machine, like the spindle of an edging-machine. As a substitute for filing it saves the files and is claimed to save three-fourths of the labor. The machines, as made by the Brown & Sharpe Company, will grind 36 inches long, 14 inches wide, and 13½ inches high.

BOILER-MAKING.

Estimates.—The following estimates of time, labor, and material are derived from actual practice under the various conditions stated, and are believed to cover very fairly the various kinds and circumstances of work. They are reduced to averages of weights handled per man per year as the most available unit of comparison, although a number of men are employed in the construction of every boiler.

In making stationary (horizontal tubular) boilers one man may be said to use in a year 9½ tons boiler-plate, 3½ tons tubes, two-thirds ton rivets, about 27,330 pounds material per year, and about 90 pounds per working day. Again, the average output per man per year in another case is 7½—"8 horse-power," 3,600 pounds boilers, or 5—"20 horse-power," 6,000 pounds boilers. The following is a more specific estimate of the material and labor in building a standard form of return tubular boiler without fire-box:

	Pounds.
Weight of 50-inch shell, 14 feet long, about	3,000
Weight of 50 3-inch tubes, 10 feet long, about	1,500
Weight of 1,000 rivets, about	90
Weight of castings in the boiler, about	210
Total	4,800

The time of labor upon this boiler is forty-eight days. Four or five men were employed continuously in building it, and it was completed in ten days. The pneumatic power riveter of the portable type was used in the work.

In making ten "10-horse power" horizontal portable boilers, three hundred days of actual labor were expended upon the ten boilers. Their aggregate weight with tubes, fire-boxes, and water-bottoms was 37,000 pounds. The average was thus about one boiler per man in 30 working days, or about 123 pounds handled per man per working day. The pneumatic portable riveter was used.

It is said that, while with hand work only, it is a good day's job for three men and a boy (rivet-heater) to drive 35 pounds, or 250 rivets per day, with the portable power-riveter one man and a boy can drive as many as 105 pounds (from 750 to 800 rivets) in a day, while rivets are sometimes made at the rate of 8 per minute.

Let us now turn to marine work. An engineer engaged in building marine boilers states that they cost about 10 cents per pound for all but the smallest sizes, which cost more, of this 6 cents being rated for labor and 4 cents for material. This estimate, it may be noted, makes no mention of investment and profit, which are taken with the labor, the actual manual labor upon the boilers costing 2 or 3 cents per pound. The following is an estimate of the weight, work, and cost of a marine boiler:

	Per cent. of weight.
12,250 pounds plating, at 4 cents per pound	57
3,860 pounds castiron, at 3 cents per pound	18
1,850 pounds forgings, at 4½ cents per pound	9
3,540 pounds tubes and rivets, at 4½ cents per pound	16

	Cents.
Estimated cost of labor per pound	2½
Estimated cost of material per pound	4
Estimated cost of investment per pound	3½
Total cost per pound	10

About two hundred and thirty days' labor were involved in building this work, upon portions of which power riveting-machines were used.

The following is an estimate of the cost of construction of a rectangular compound marine boiler of 60 tons, government work, hand-riveted in place and requiring much flanging:

Material, 60 tons, at 7 cents per pound	$8,400
Labor, 20 days, by 22 men	9,600
Total	18,000

The work involved reduces to 4,400 days per man. The daily labor by crafts and wages paid was as follows, the average rate of wages for skilled and unskilled work being about $2 20 per day:

2 boiler-makers or fitters, at $3 per day	$6 00
2 flange-turners, at $3 per day	6 00
6 riveters, at $2 25 per day	13 50
3 rivet-heaters, at $1 50 per day	4 50
6 caulkers, at $2 25 per day	13 50
3 helpers, at $1 50 per day	4 50
Wages per day	48 00

The total cost of boiler being 15 cents per pound; the cost of labor was 8 cents, and of material 7 cents per pound.

Machine plant and machine methods.—In boiler-making the number of pieces of power machinery are not numerous as compared with the machine-shop plant. In one establishment a 25 horse-power engine operates 4 blacksmith-shop tools, 4 tumbling-barrels, 1 blower, 8 boiler-yard tools (punches, shears, riveter, and rolls), 1 air-compressor for riveter, and 2 hoists. Some of this machinery is, as will be seen, for foundery and general purposes. A boiler-shop with an annual output of two or three thousand horse-power of stationary boilers has the following principal machinery: 2 punching-machines for boiler-plate, one with spacing-table and apparatus attached; 1 machine for scarfing or planing boiler-plates on the edges; 1 set rolls for boiler-plate. Hand-riveting is the practice in this shop.

Another shop with a considerable number of operatives has 2 punches, 1 pair shears, bending-jaws, and straightening-rolls. Most of the operatives are employed in setting up, holding iron plates for punching, ratchet-drilling, marking out and riveting (all of which is done by hand).

Many large shops, especially in the south and west, rely upon hand-riveting, but steam, hydraulic, pneumatic, or other power riveters are being rapidly introduced, and with such manifest advantages that their general employment is only a question of time. A size of riveter made by Wm. B. Bement & Son for large work is called a 72-inch riveter, the distance from the center of die to the bottom of opening being 6 feet. The stake or anvil member of the riveter is made of a superior quality of wrought iron in order that it may be made small enough to permit the riveting of small flues. The riveter has a balanced steam-valve, and the steam which drives the rivet is made to return the piston to beginning of its stroke before escaping.

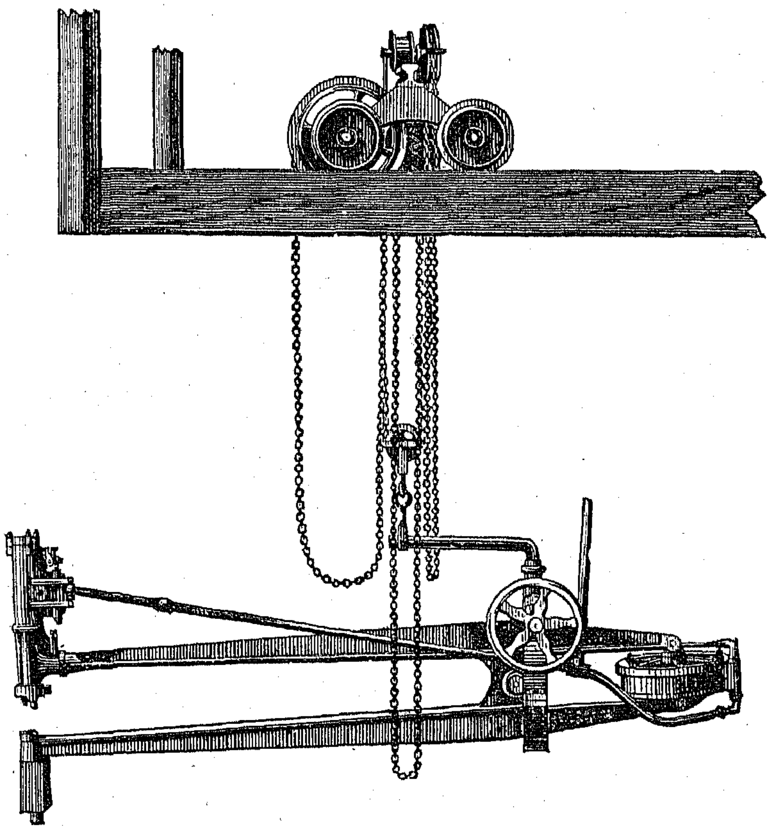


FIG. 8.—PORTABLE PNEUMATIC RIVETER.

A stationary riveter employed at the Globe Iron Works, Cleveland, Ohio, under 50 pounds steam strikes a 40-ton blow.

For work on stationary and portable boilers the portable pneumatic riveter is becoming a favorite tool, being approved by some of the most reliable manufacturers, such as Lowe & Watson, Lane & Bodley, Griffith & Wedge, the Atlas Engine Works, and many others, as furnishing better work and a productiveness greater (by about 4 to 1) than that of hand labor. The Allen pneumatic portable riveter usually operates with the boilers in a horizontal position, instead of being hung vertically from cranes as with the fixed riveters. It is claimed that with hung work the portables can be operated by fewer men than the fixed machines, that they make tighter work, and drive with equal rapidity. An illustration (Fig. 8) is presented of this riveter, showing it suspended from an overhead track. It may be shifted to various positions, and is often used in connection with a peculiar saddle of rollers so that the boiler may be turned readily in making cylindrical joints. The rollers are turned by a gear-wheel, and have holes or pins by which they turn the boiler working either with the rivet-heads or the punched holes of the boiler. (In hand-riveting such work the boiler rests upon the long beak of an anvil extending within the shell, while an endless chain from a crane above passes around the outside of the boiler and enables the workmen to shift its position from rivet to rivet.)

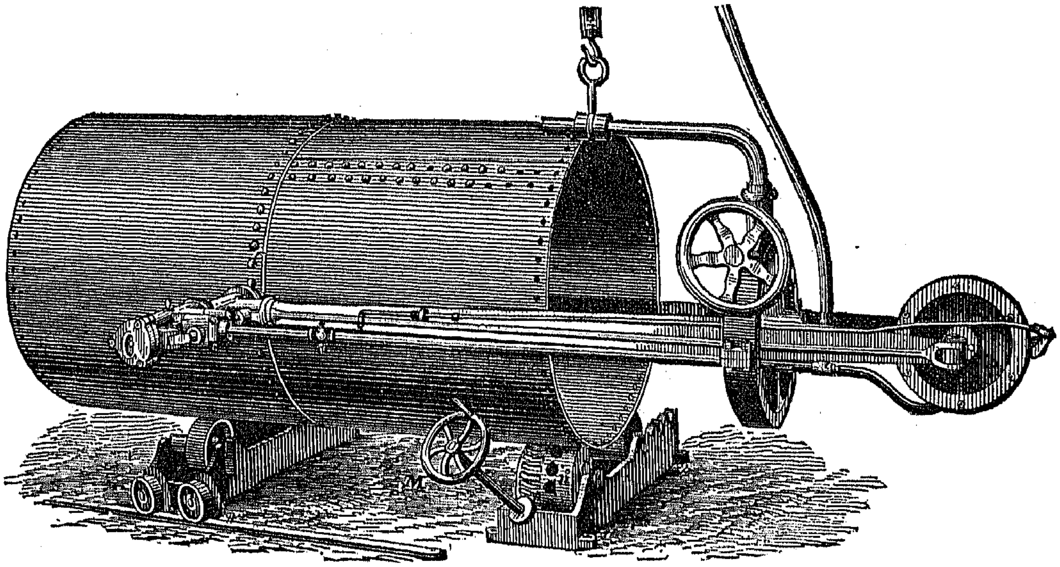


FIG. 9.—MANNER OF HANDLING BOILERS IN RIVETING.

The operation of the pneumatic portable riveter may be briefly described as follows: The riveter consists of two long levers held at their axis or fulcrum in a ring with a worm-wheel so as to work in any axial position. One end of the apparatus has a pressure-cylinder between the lever-arms, the other end a pressure-cylinder with piston and riveting-hammer on one arm and a die or anvil on the other. The machine first closes upon the plates, flattening the burr before riveting, and it then presses them with about 1,200 pounds pressure while the rivet is being driven. The rivets are formed, not by a single blow, but by a succession of blows, as in hand-riveting. The riveter makes from 150 to 200 strokes a minute; it forms the head of a three-quarter-inch rivet in six seconds, and easily finishes two rivets a minute. A rivet-boy places the rivet and lets the pressure into the large cylinder which closes the lever upon the plates. Then an operative admits pressure to the hammer-cylinder and the rivet-head is formed. The machine saves the labor of two men, one riveter and one for holding the work.

In the air-compressor used with this riveter, the steam- and air-cylinders are in line and have the same bore and stroke, 7 by 7 inches. The valves have a positive motion and the reciprocating parts are made designedly heavy.

So far as I can ascertain, the use of riveting-machines is no more advanced in England than in this country, some machines of American manufacture being used in England. Both fixed and portable machines are, however, in use in the north of England shipyards.

The multiple plate-drilling machine of Thorne and De Haven is employed for drilling boiler-plates and mud- and fire-box rings. This machine is described under the head of locomotive manufacture, but the general introduction of such machinery is prevented by the fact that work is not of a sufficiently large and uniform character to warrant the expense. The British board of trade allow such advantages in the inspection of drilled over-punched boilers that it is made an object to incur the extra cost of drilling, and in the large marine shops in England boilers are commonly drilled in place. Considering that in this age of steam a person traveling or dwelling in a large community is scarcely ever out of the range of liability to injury from a boiler explosion, anything which affords greater security is an object of general concern. In this country boilers are usually punched, but for convenience and rapidity of execution American drilling machinery is unsurpassed and will undoubtedly work its way into more extended use. On some classes of straight work it is claimed that with the use of multiple drills holes can be drilled about as rapidly as they can be punched singly, but under ordinary conditions (although it is not easy to make exact comparisons) drilling boiler-plate may be said to cost about five times as much as punching.

Spiral punches have been used which do not strain the iron as much as an ordinary punch, and to obviate the well-known loss of strength due to punching, holes are often punched small and reamed out to full size; or after punching holes full size, the plates are sometimes reheated and cooled slowly, annealing the iron and restoring its strength. In connection with punching machinery many shops have improved labor-saving facilities in the way of shifting- and spacing-tables. The more primitive method of handling pieces of boiler-plate was to rest them upon an ordinary table or hang them from a crane, while half a dozen or more laborers gathered around to move the plate under the punch.

Flanging machinery is more generally used in England than here. It is costly, and operating as it does by means of formers, it is only applicable to a uniform character of work. But its employment is very desirable, for hand-hammering even to a former (common practice) strains and corrugates the iron. Iron of a grade which cannot be safely flanged by hand-hammering may be easily handled with a flanging-machine which turns the edge by an even and uniform pressure.

Ten or twelve years ago the steel manufactured was too brittle and treacherous for boiler-plates, but it is now made (low steel) of a quality ductile for flanging and admirably uniform. Its use ordinarily gives an advantage in the neighborhood of 10 per cent. in lightness for the same strength as iron. At present we even hear of cast-steel boilers and boiler parts, and the next decade will probably witness some important modifications of present practice in the use of metals in both engine- and boiler-making.

WEIGHT OF ENGINES.

In stationary engines for manufacturing purposes there is great variation in weight both for similar powers and for similar capacities of cylinder. Some long-stroke, automatic cut-off engines weigh twice as much and cost about three times as much as throttle-valve engines of the same cylinder capacity.

It might be expected that for the same cylinder capacity engines having the greatest cylinder surface would weigh most, but there are many exceptions to this rule, even in engines considered of similar strength and design. A long-stroke engine, having a longer crank than one of short stroke, has usually a higher bed, which requires increased weight.

A table is presented showing ranges of weights usual in stationary engines. Many heavier engines are of course built, but the table exhibits the ordinary range of weight. In column A are given a series of cylinder capacities in cubic feet; in column B the ratios of length of stroke to diameter of bore for the several cylinders. In column C are stated the ratios of number of square inches interior cylinder surface to each cubic foot of cylinder volume. It will be seen that these ratios of surface to volume decrease so rapidly with the increase of cylinder capacity that the difference due to proportions of cylinders is often obscured. In the columns D, E, F, G, H, J, K, and L are given weights of engines in pounds per cubic foot of cylinder capacity. Columns D and E give these weights for automatic cut-off engines, the engines alone, and columns G and H for the same engines, with the usual weights of fly-wheels added. Columns F and J give the weights per cubic foot of cylinder for a plain slide-valve engine, without and with the fly-wheels respectively. Columns K and L show the weights per cubic foot of cylinder for two designs of slide-valve engines with pulley fly-wheels.

In some engines the progression of sizes is arranged so as to get a large number of sizes with a small number of patterns by repeating the use of particular parts in several sizes. This, of course, causes a slight redundancy of weight in some of the sizes. But, even where there is a separate design for every size, the weights per cubic foot of cylinder often vary from any uniform rate of progression. I note one case, in a series of slide-valve engines of similar design, in which the cylinder capacity of one size is increased by one-fifth in the next with scarcely any increase in weight.

A.	B.	C.	D.	E.	F.	G.	H.	J.	K.	L.
0.09	1.60	1,632								8,888
0.13	1.33	1,594								7,231
0.19	2.00	1,487			6,053			8,684		
0.23	2.33	1,392	9,130			13,478				
0.27	1.71	1,257			4,352			6,296	8,518	
0.31	2.00	1,241	7,742			11,613				
0.34	1.50	1,182							8,235	5,412
0.41	1.75	1,103	7,073			10,975				
0.46	2.00	1,092			5,522			7,500		
0.52	1.88*a* 1.55*b*	1,039*a* 1,004*b*	6,846*b*			9,808*b*			6,538*a*	
0.59	1.77	980			5,212			7,118		5,424
0.63	1.40	947	5,873			9,048				
0.66	1.68	938							6,818	
0.72	1.00	916			4,965			6,944		
0.81	1.80	892	6,584			10,244			6,913	
0.91	2.00	863	6,153		4,022	9,450		6,264		6,044
0.99	1.04	819							6,667	
1.18	1.50	771							6,610	
1.20	2.00	791	5,250			7,916				
1.31	1.66	748	5,649		4,278	8,703		6,183		4,962
1.57	2.00	720	4,904		3,668	7,452		5,860	6,269	
1.78	1.43	667			3,264			5,168		
1.90	2.00	669	4,322			6,834				
2.13	1.72	639	4,789		3,061	7,840		5,023	5,868	
2.36	3.00	671		5,085			7,027			
2.48	2.00	620	4,436			7,177				
2.79	1.50	576			2,301			4,337	4,838	
3.06	2.00	577	4,346			6,634				
3.48	1.87	549			2,529			4,263		
3.53	1.33	527			3,056			5,241		
3.72	2.00	540	4,032			6,264				
3.74	3.00	576		4,216			6,631			
3.82	1.44	517	4,188			6,361				
3.93	1.76	523							3,944	
4.35	1.20	491			3,149			4,736		
4.42	1.66	490			2,920			4,638	4,525	
4.72	1.30	479	4,237			6,356				
4.88	2.03	517		4,508			6,762			
5.30	2.00	479	3,585			5,472				

A.	B.	C.	D.	E.	F.	G.	H.	J.	K.	L.
5.45	1.50	461	......	......	3,234	......	......	4,964	......	......
6.19	2.33	450	......	3,037	......	......	6,037	......	......	......
6.53	1.80	442	......	......	......	......	......	......	3,829	......
7.06	2.66	438	......	3,966	......	......	5,949	......	......	......
7.25	2.00	433	3,448	......	......	5,103	......	......	......	......
7.62	2.10	428	......	3,674	......	......	5,512	......	......	......
8.71	2.40	418	......	......	......	......	......	......	......	......
9.22	1.91	397	......	3,471	......	......	5,206	......	......	......
9.66	2.00	393	3,105	......	......	4,658	......	......	......	......
10.54	2.18	387	......	3,416	......	......	5,123	......	......	......
12.57	2.00	359	3,174	3,182	......	4,773	4,773	......	......	......
14.74	1.85	338	......	2,992	......	......	4,477	......	......	......
15.71	2.50	345	......	2,896	......	......	4,550	......	......	......
18.44	2.31	323	......	2,657	......	......	4,175	......	......	......

CYLINDER CAPACITY AND COST.

The following diagram exhibits comparatively the relations of cylinder capacity, weight, and cost in steam-engines of the horizontal plain slide-valve type, rated at from 8- to 100-horse power.

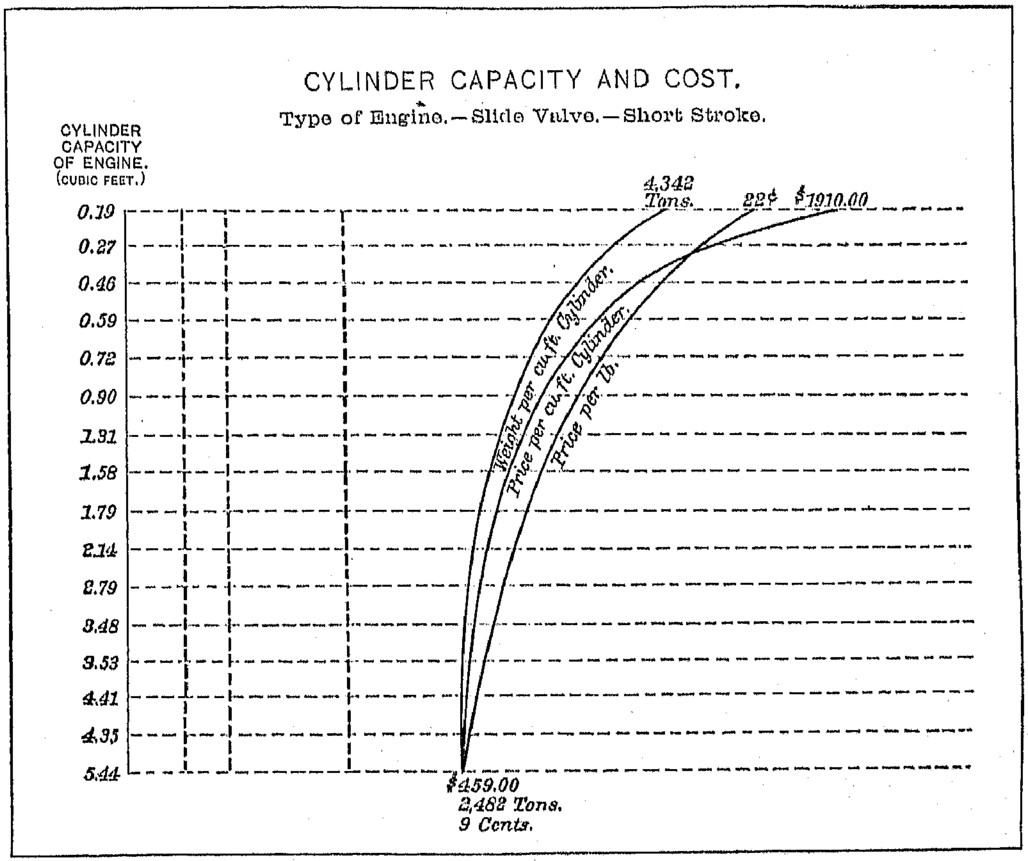


FIG. 10.

The column of figures at the left represents the cylinder capacities of the engines in cubic feet. One line shows the fall in price per cubic foot of cylinder capacity from $1,910 per cubic foot for 0.19 cubic foot to $459 per cubic foot for 5.44 cubic feet. Another line represents the decrease in weight per cubic foot of cylinder capacity from 4.342 net tons per cubic foot to 2.482 net tons per cubic foot. A third line represents the decrease in price as rated by the pound, being from 22 cents for a 0.19 cubic-foot engine to 9 cents for a 5.44 cubic-foot engine.

For ready comparison the three curves are started at one point, the three base lines corresponding with the values stated.

The prices of the engines, as per the following table, are seen to increase less rapidly than the cylinder capacities:

Capacities.	Prices.	Capacities.	Prices.
0.19	$362 90	1.79	$1,133 07
0.27	375 84	2.14	1,217 66
0.46	511 08	2.79	1,380 63
0.59	561 68	3.48	1,569 48
0.72	627 84	3.53	1,796 77
0.90	674 10	4.41	1,975 68
1.31	926 17	4.35	2,248 95
1.58	1,017 52	5.44	2,496 96

It is obvious that no formula can truly exhibit the relative decrease of price and capacity which does not consider the actual sizes of engines compared. The examples cited present an unusual degree of uniformity, a line of engines rated at uniform piston speed, and of similar excellent workmanship and finish. Between different styles and qualities of engines there can be no very definite comparison.

After we have passed the limit of equality of stroke and diameter, long-stroke engines usually weigh more, but short-stroke engines usually cost more by the pound for the same cylinder capacity and workmanship. For the same cylinder capacity, a finely-built closely-fitted engine may cost twice as much as an engine of inferior workmanship.

In attempting to discuss in general the most profitable ratio of expansion, based upon the size of cylinder and cost of engine, as well as upon the cost of fuel, it is very easy to make formulas, but these may only serve to perplex the tyro by opening for him a road of scientific investigation which leads to no useful principle or result. The longevity of an engine of the best present workmanship and material is unknown; neither material nor quality of work can be adequately expressed by formula, and the cost of repairs, an element increasing with the age and service of the engine, can only be guessed. The exact determination of the so-called point of economic cut-off could be of utility only at one time, viz, in the selection of an engine, while cost of fuel and rates of interest are subject to variations from time to time, and the work required to be done varies considerably in every case. As these variations more than cover the difference in economy between an engine of the greatest efficiency and one of less efficiency at a cost so much smaller as to more than compensate for the loss, the determination of the minimum is useless. It is useless to the manufacturer, for he must build many sizes of engines; useless to the owner, for his investment is already made; useless to the buyer, for it can not cover the flexibility of his future expenses and requirements.

There is an inherent fallacy in introducing commercial cheapness into a formula upon the same basis as engineering efficiency. Economy is a question of absolute costs and not of the relative costs of fuel and machinery. For example, the lower the cost of the engine the greater becomes the relative cost of fuel, and the earlier within limits it might be argued, may be the cut off economically employed. But, as a matter of fact, we find the best engines of fine workmanship, liberal capacity for the speed, and of high cost for a given cylinder capacity, in sections where fuel is dearest, and cheaper and poorer engines in sections where fuel is cheapest. A minimum of expense, based on cost of engine and ratio of expansion, can not be practically established on account of the neglect of the element of quality, an element which enters into both terms of the cost, being directly as the first and inversely as the running cost, and definitely assignable in neither. Cost also depends so much upon differences in automatic valve-gear details and general finish that such variations are often enough to obscure considerable differences in cylinder capacity. The manufacture of one of the best and most economical engines ever designed (the Babcock & Wilcox) has been abandoned on account of high cost of construction, and some of the most recent forms of automatic engines have no more parts than plain slide-valve engines.

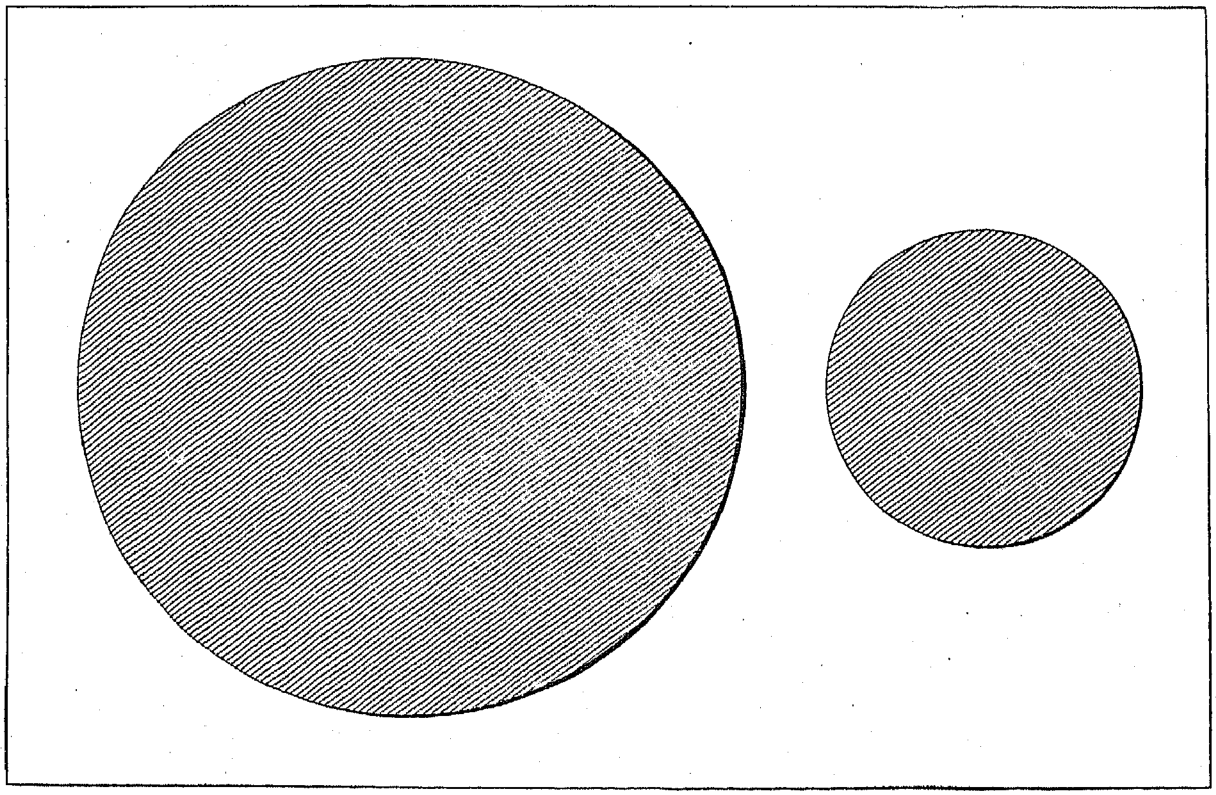


FIG. 11.—SIZES OF HIGH AND LOW SPEED SHAFTS.

THE SPEED OF ENGINES.

Fifty years ago American mill-work was modeled after the foreign practice of that time, the shafts being of wood and square in section, with cogs wedged fast, and barrel-pulleys or wooden drums clamped upon the shafts. The earliest iron shafts were also made square, but these were displaced by round iron shafts, to which cast-iron pulleys were keyed on, (*a*) the pulleys being sometimes halved. Heavy, slow-moving shafts have been gradually displaced by light, high-speed shafts, the number of revolutions per minute having advanced from 30 in 1822 to upwards of 200 in 1880. "The practice of high-speeded shafts and the entire substitution of belting for gear-wheels belong essentially to this country".—(Sellers.) The substitution of belting for gearing in the transmission of power enables a higher speed and smoother motion to be realized and at less expense. More rapid velocity permits the use of lighter shafting. To give an idea of this, a small sketch is presented (Fig. 11), showing approximately the relative cross-sections of shafts transmitting a given power with a given factor of safety (which for mill-shafting is necessarily a high one). The larger shaft may be taken as running at 30, the smaller at 300 revolutions per minute. The change in speed being tenfold, the weight is reduced to considerably less than one-fourth.

The following is an account of one of the earliest cases of the introduction of (then) comparatively high-speed shafting displacing the old square shafts: Colonel Roswell Lee, superintendent of the Springfield National Armory, obtained the services of some very good mechanics from North's pistol factory in Middletown, Connecticut, among them, Nathaniel French. In 1831 and 1832, shortly before Colonel Lee's death, a new shop was erected at what are known as the Springfield water shops, and Mr. French was intrusted with the duty of designing the motive machinery. In place of the cumbrous square shafts then in vogue, he put in everywhere small round shafts and spindles (about half the previous diameter), to the great concern of old mechanics, who predicted that some of the smaller shafts would "wear out in a month", a prediction which, it is needless to say, was by no means realized.

The improvement in the saving of power by the use of light transmissive machinery can hardly be reckoned. In the aggregate it is enormous, and advances are still being made in this direction. Only within a few years it was the general custom to sell pulleys by the pound, with every inducement to the maker to load shafts with as much cast iron as he should think conscionable. When some enterprising manufacturers started out to put upon the market a form of cast-iron pulley designed to be as light as was compatible with the necessary strength, some argument was required to dispel the prejudice in favor of superfluous weight. Now, however, greater lightness is secured by making pulleys with wrought-iron rims. These pulleys, as made by the Hartford Engineering company, have cast-iron hubs and spokes, the arms or spokes being straight, light, and more numerous than usual, and with bracket offsets at the ends, about which the sheet-iron rims are bent, and to which they are riveted after drilling. They are faced and finished on grindstones, specially arranged with automatic feeds, so that the work is rapidly done, and the greater expense of turning is obviated. The resulting pulley is very light, and a development in the direction of higher speeding. It may also be noted that iron pulleys with wood rims are being introduced in some classes of service, for the sake of lightness.

For mill purposes the first double-acting engine in New England was built in 1808 by Philip Allen, and in 1833 Z. Allen introduced, at the works of the Wadsworth Steam Engine company, the engine with variable cut-off valves governed by a revolving ball-regulator for the expansion of steam. The Corliss engine works were started in 1848. It is not here proposed to enter upon so wide a subject as the history of the steam-engine, but in noting these early changes in shop practice the influence of the introduction of types of engine is important, and Rhode Island appears to have been the pioneer state in this march of improvement. Higher speeds first resulted from improved engines and machinery, and the tendency is still strong to push to the utmost the advantages of high rotative speed in engines. Some of the more conservative builders maintain that with the present weight and strength of materials high speeding is not in many cases economical. But, on the other hand, it is claimed that the tendency to use smaller cylinders and more rapid movement promises to go to much greater lengths in the future, and since the velocity of engine travel is still far within the velocity due to the pressure of steam, there is no practical limit to speed within that due to the weight of parts. The question of speed is a relative one, the low speeds of to-day being equal to the high speeds of earlier times, and clearly illustrating a tendency which has not reached its limit.

In engines of the Corliss type a certain speed is advantageously reached, and the excellence of this engine is such as to challenge a halt in the advocacy of higher speed. The Corliss engine, compound condensing, and with steam-jacketed cylinders, if run with tight valves, at the medium speed available with a drop cut-off, at this time may be justly considered the criterion of high economy in steam consumption. But speed is a highly economical factor. It reduces the weight and cost of machinery very greatly for the same power and economy of steam. Its value as equivalent to that of high pressures and compounding is well expressed by Mr. H. A. Hill (Boston):

> Experiments with three boats of the same size by the United States Government gave about 32 per cent. of steam condensed per hour at an initial pressure of 40 pounds in a single cylinder engine; about 26 with 70 pounds initial in a single cylinder, and about 6 per cent. in the high-pressure cylinder of a compound engine, while the low-pressure cylinder of the same engine showed about 27 per cent., an average of about 17 per cent. in the two cylinders of the compound engine. Now of these methods of economizing, one at least, that

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[a] Wooden pulleys are still in use at Springfield armory, Massachusetts, and in some drop shops, and are again becoming an article of manufacture for special uses.

of the higher pressures, gets its results mainly from the fact that it puts the required power into a smaller cylinder with less condensing surface. Increase of speed does precisely the same thing. It does the required work with a smaller cylinder, and so less area to condense the steam.

We naturally credit the low-speed engine with the greater durability, but high speed results in such a reduction of stress that it is easy to provide bearing surfaces much more ample for the same pressure than those which may be provided for a low-speed engine. By the laws of solid friction the advantage would then appear to be with the high speed; but the advantage of low speed, even with a greater pressure per square inch, is that there is more time for conducting away the heat of friction. To reap the advantage of high speed the lubrication of the bearing surfaces must be well maintained, and if methods of cooling fail, the disastrous effects come more quickly under high speed. But with proper engineering precautions the durability of high-speed engines is surprising. Mr. J. W Spangenberg, Warren, Ohio, has called the attention of the writer to the service of direct-attachment saw-mill engines. These constitute an exception to the low speeds of early practice, and pains have been taken to verify from several sources the statements of the remarkably high speeds of engines for saw-mills as used many years since.

The following account of one of these engines is given by Mr. C. Strom, Bristolville, Ohio:

> The engine is 9-inch bore, 12-inch stroke, running a direct-attachment saw-mill. We run it all the way from 400 to 600 (1,200 feet lineal) and perhaps 700 revolutions per minute. We run some of the time a 60-inch saw, part of the time a smaller one. We can cut 1,000 feet of 1-inch boards in one hour, and think the engine with 75 or 80 pounds pressure will do more than that. The engine has been in use over 16 years, and has been run the greater part of the time, in fact almost continuously. The cylinder was bored once only in this time, about 7 or 8 years ago, and since then one set of new piston-rings has been put in. The bearings are all in good order, with all the original brasses except those on the cross-head and on the main wrist of the crank. These two have been replaced as they got worn loose in the straps. These brasses are lined with Babbitt metal. The slides or ways are *not worn at all*. The cross-head is lined with Babbitt metal, which has to be replaced occasionally, perhaps once a year. The engine is governed by the sawyer with a sawyer's or butterfly valve. We use now a half pint of good cylinder oil per day, with an automatic oiler. Before this we used a common old-fashioned oiler, the cylinder *running dry half the time.*

The engine has always run smoothly, but runs more easily with the automatic oiler.

A (10-inch bore by 12-inch stroke) saw-mill engine used by Snyder & Son, of Piqua, Ohio, has run over 8 years, averaging a million feet of hickory sawed per year. It has turned out 15,000 feet in 10 hours. It runs at 600 to 1,000 feet per minute with the saw in the log, 200 to 300 feet gigging back. It requires 1 quart of cylinder, 1 quart of engine, and 1 quart of black oil per week. In the 8 years the only repair has been one new set of piston-rings, the engine continuing to run smoothly without reboring of the cylinder or replacement of the connecting-rod boxes.

Apart from these exceptional cases, high-speed engines driving the main shaft direct at 125 to 175 revolutions per minute were used 18 or 20 years ago (1860), and for saw-mill muleys, as stated by Mr. J. W. Thompson, over 30 years ago (1850). Most flouring-mills and saw-mills were formerly run by throttling-engines of long stroke and low rotative speed, and these were largely superseded by short-stroke throttling-engines, which are in turn giving place to automatic engines.

Apart from all question of automatic cut-off, comparing throttling-engines, the advantages of high speed are immediately shown in reduced fuel consumption and boiler capacity required, so that a high-speed throttling-engine well governed and proportioned for its load may exhibit a good showing compared even with an automatic engine.

About 1850 the Corliss engine began to be introduced with great results in the economy of fuel, due to its automatic control of the admission of steam. The invention of George H. Corliss, its valve-gear principle became adopted by numerous builders of engines both in this country and in Europe. No other device has given greater prestige to American engineering. The engine is more extensively used for stationary purposes than any other type of large automatic.

The next move was to secure higher speed by the use of positive cut-off valves for automatic control of steam admission. This, like the Corliss cut-off, was a distinctive development of American engineering skill. The Porter-Allen engine was brought into prominent notice at the Paris exposition (1867), and the Buckeye engine was a design developed a few years later. At the Paris exposition high-speeding received another aid in the introduction of Richards' improved indicator for testing the power of engines. The Porter-Allen engine derives its name from the combined inventions of John F. Allen and Charles T. Porter, the admission valves being the invention of Allen, and the general design of the engine due to Porter, whose name is associated in particular with the governor and the framing or bed of the engine, both of which have been largely copied. The Buckeye engine was developed mainly under the patents of J. W. Thompson. The device of a "shaft-governor" is attributed to J. C. Hoadley; but the Buckeye engine, employing a design of shaft-governor in connection with balanced or relieved flat valves, commanded a commercial success which has made it a representative type.

A piston speed of over 1,000 feet a minute has been employed in large sizes of both of the positive cut-off engines mentioned. Large Corliss engines are rated to be run as high as 720 feet a minute. Usual speeds are less even for positive cut-offs. H. A. Hill gives as the present status of good high-speed usage 300 to 200 revolutions for engines of 50 horse-power and under, 160 to 125 revolutions for 50 to 150 horse-power engines with 20- to 30-inch strokes, and 120 to 90 revolutions for 200 to 800 horse-power engines with 30- to 48-inch strokes.

In 1869 the Novelty Iron-Works, of New York, commenced the manufacture of a new slide-valve engine with the Horatio Allen style of bed (Fig. 14). These were made in standard sizes from 5 to 350 horse-power in two series, with long and short strokes and various ranges of speed. The short strokes were less than two diameters of cylinder and the long strokes over two diameters. The speeds of engines from 25 to 50 horse-power were rated at from 131 to 45 revolutions per minute for the long and 212 to 78 revolutions for the short strokes. The speeds of engines from 60 to 150 horse-power were rated at from 104 to 40 revolutions for long (24- to 48-inch) strokes and 168 to 63 for short (15- to 30-inch) stroke. The speeds of engines from 175 to 350 horse-power were rated at from 87 to 33 revolutions for long (36- to 60-inch) strokes and 42 to 142 for short (21- to 48-inch) strokes.

The latest development is in the usage of what are known as single-valve automatics. These govern by aid of variable compression acting jointly with variable admission. This principle was first dwelt upon by Mr. Harris Tabor. The compression goes far to reduce loss by clearance and internal condensation. As a measure of economy "there is nothing so promising which comes with so little cost". (Tabor.) The single-valve automatics are not so much designed to produce absolutely the most economical results as to get "the most for the money" with the best uniformity of speed. It is argued that it is "the attempt to save the last per cent. of fuel" which involves a cost overbalancing the slight advantage gained.

The Richards indicator was introduced in 1867 as a practical device for determining the power of engines speeded so high as to render worthless the indications of instruments previously used. The requirements of high speeds have now so advanced that the Richards is held suitable only for the indication of low-speed engines, numerous devices, such as those of Thompson, Brown (Crosby), and Tabor, having been invented for the indication of powers under higher speed.

The following tables make an exhibit of the range of speed as practiced in various kinds of work. They are gleaned from data furnished by the Buckeye Engine company, Salem, Ohio, of the usage of their engines. There is first a table showing fastest, slowest, and average number of revolutions per minute for various classes of work, the corresponding power or average power being cited as developed in each case. This conveys a good idea of the average size of engines to which the speed bears reference. The usual rated power is as developed with a mean effective pressure of 35 pounds from an initial pressure of 80 pounds cut-off at about one-fifth of the stroke. Of course different classes of work embody different conditions and different engine powers, in the light of which the figures have to be interpreted. A second table shows, in a similar manner, the ranges of piston speed in various classes of service:

TABLE I.

Revolutions.

Kind of service.	Fastest.		Average.		Slowest.	
	Revolutions.	Power.	Revolutions.	Power.	Revolutions.	Power.
Cotton and woolen mills	215	20	150	133	100	600
Electric lights	215	150	150	65	100	150
Stove works	200	25	151	46	100	100
Machine-shops	225	30	142	62	75	40
Paper mills	215	30	137	96	85	125
Malleable iron works	150	60	132	50	100	50
Flouring-mills	225	25	120	80	85	150
Iron works (rolling, etc.)	150	200	120	93	100	80
Print works	160	1,000	127	714	102	250
Wood-working	160	60	120	50	70	150
Mining	175	70	104	178	83	350
Wire-mills	100	175	100	157	100	140
Silk mills	110	80	95	80	80	80
Grain elevators	96	200	92	422	80	90
Brass works	120	55	91	72	75	60

TABLE II.

Speed in feet per minute.

Kind of service.	Fastest.		Average.		Slowest.	
	Feet per minute.	Power.	Feet per minute.	Power.	Feet per minute.	Power.
Print works	960	1,200	788	714	500	120
Mining	800	400	577	178	350	50
Wire-mills	600	175	566	157	533	140
Grain elevators	700	1,200	536	422	420	90
Paper mills	800	125	527	96	400	30
Cotton and woolen mills	626	600	500	193	450	40
Electric lights	626	80	506	65	450	40
Flouring-mills	600	200	493	80	400	60
Silk mills	600	150	485	128	340	80
Malleable iron works	540	80	471	375	375	30
Wood-working	600	75	466	89	373	75
Iron works (rolling, etc.)	584	70	463	93	350	40
Machine-shops	666	200	461	62	250	40
Stove works	500	100	441	46	350	30
Brass works	480	55	418	72	350	60

A graphic exhibit of the effect of speed and automatic cut-off upon the size of engine is shown in a diagram comparing four sizes of engines of nearly the same power between 100- and 125-horse power.

A and B represent the cylinder sizes of automatic engines with steam at 80 pounds initial, cut-off at one-fourth stroke. A is speeded at 78 revolutions and is a drop cut-off. B is speeded at 150 revolutions and is a positive cut-off.

C and D represent the cylinder sizes of throttling or plain slide-valve engines. C is speeded at 70 revolutions, D at 600 revolutions (as tested by the speed-indicator).

All of these are practical serviceable engines in competition on the market to supply like powers, although not equally suitable for different purposes. D represents a direct-attachment saw-mill engine, of the durability of which, despite its small proportions, we have had some evidence. As compared with B, an example of a high-speed automatic for electric lighting, it is seen to be far in advance in point of speed, although antedating the high-speed automatic. Comparing A and C, it is plain that steam is so throttled and wasted by C that A, with steam cut-off at one-fourth of its stroke, develops equal power, though a smaller bore of cylinder. A is also higher speeded, and shows the advance in speed made by the drop cut-off automatics over the early types of throttling-engines.

With D the economy is very much better than with C, for the steam is used quick and hot, the best regulation of speed is attainable and throttling becomes less injurious to efficiency. The piston-speed of A is 556, of B 600, of C 420, and of D 1,200 feet a minute. With the same mean effective pressure per square inch the pressure coming on the crank-pin would be in the proportion of about 6,000 for A, 5,000 for B, 11,000 for C, and only 2,500 for D. In fact, C uses steam so much throttled that the mean effective pressure is less, and the average pressure upon its crank-pin would be about 8,000 pounds.

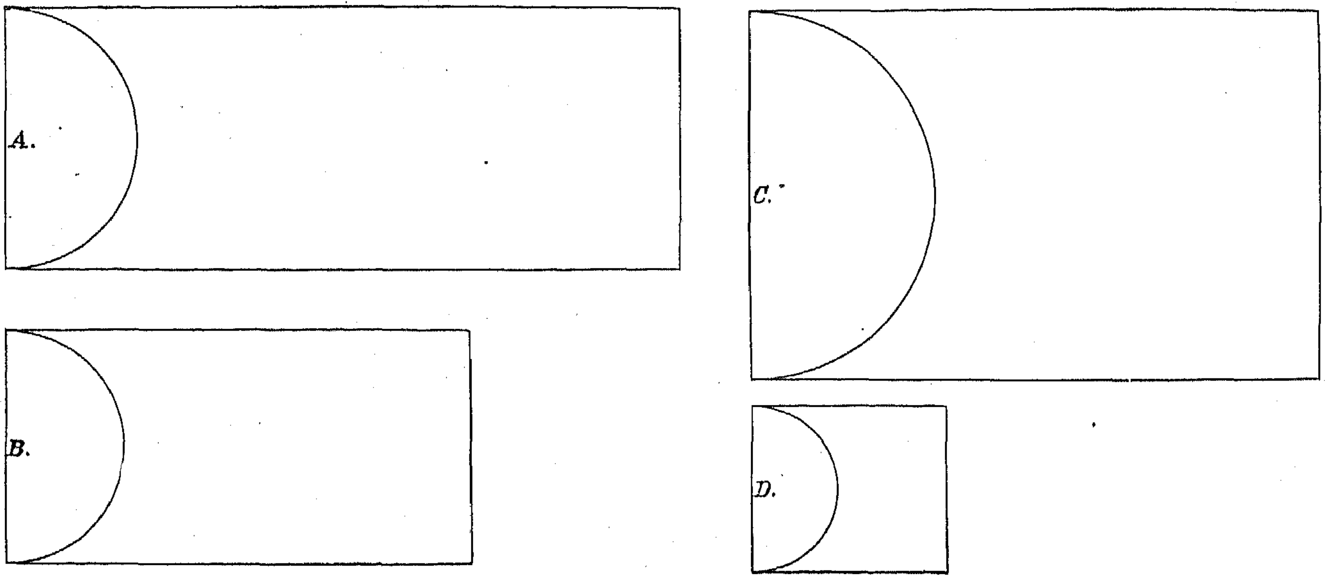

FIG. 12.—COMPARISON OF ENGINES OF LIKE POWER.

Mention has been made of the use of belts, instead of gears, as an American improvement, but a still greater innovation is in progress. For low speeds a pulley fly-wheel with belt is used, but for high speeds of engine, belts are discarded, and by means of a coupling and balance-wheel direct connection is made to the end of the line-shaft. Both positive and drop cut-off engines are used in this way. The practice is mainly employed in rolling- and in flouring-mills, but the tendency is to make it more general for other classes of work. A notable example of the employment of this practice in shops is afforded by Colt's armory, Hartford, Connecticut, in which the principal power is furnished by four Porter-Allen engines coupled to the main shaft. As this is one of the most notable instances of direct connection employed in a large machine-shop, an illustration is presented of two of these engines, which conveys a very good idea of the valve-gearing, and of the general arrangement for this class of service. One sectional elevation is shown, the section being through the center of the cylinder. There is also shown a side elevation, taken so as to exhibit the governor and its connection with the link-motion. The cylinders are beneath the level of a platform of the factory floor, which permits the use of a good length of connecting-rod, and the location of the crank-shaft near the ceiling at the usual height of mill shafting. The shaft makes 130 revolutions per minute. The cylinders are 12½ inches in diameter by 24 inches stroke, and are rated at 75 horse-power each, or 300 horse-power for the four. The engines were built in 1867 from the designs of Mr. Charles B. Richards.

The first Porter-Allen engines which were applied to rolling-mill service were put in the Albany and Rensselaer Steel works on the recommendation of Mr. A. L. Holley. This was in 1876 or 1877. The engines had 18 by 20 and 22 by 36-inch cylinders; and in 1880 a 22 by 36-inch engine was put in to drive a rod-train, and this was driven at 200 revolutions per minute, or the great piston speed of 1,200 feet a minute, the piston going a mile in less than 4½ minutes. The operation of these high-speed engines has been very satisfactory.

There are examples of Corliss engines coupled to line-shafts at from 50 to 110 revolutions, principally in the flouring-mills of the west. With the high-speed engines, from 100 to over 200 revolutions per minute are usual for this class of service, and it is stated that, owing to the reduced weight of engines, fly-wheels, and framing, the cost is sometimes reduced as much as one-half from the cost of belted engines of the same power. This is a characteristic American practice, and it is justly regarded as a great advance in economy.

Among the various types of automatic cut-off engines, competition has been so active that there is not one of the leading designs which has not been perfected so as to exhibit a high degree of economy, and the matter of selection is often reduced to a question of wear and workmanship rather than to the exhibits of close results in competitive trials, whose conditions may not be maintained in practice.

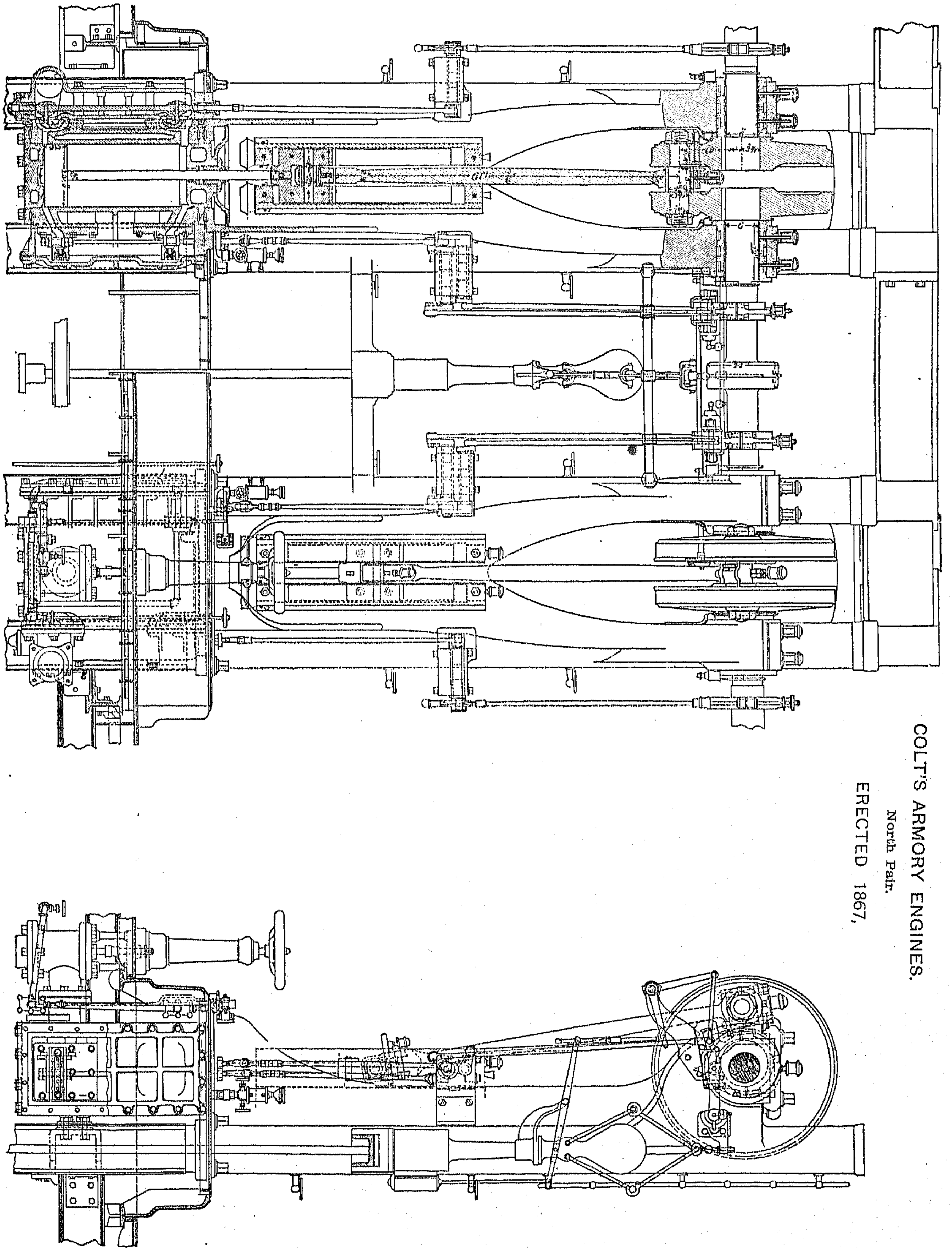

FIG. 13.—COLT'S ARMORY ENGINES.

Into the conflict of trade opinions we cannot enter. The nature of service will often determine the selection of a proper speed. "As between the standard automatic engines of to-day, the inherent differences as to economy are so small as to belong rather to expert investigation than to practical account." It is truly said that the causes of fuel waste are more often to be found in the conditions under which the engine is compelled to work than in the engine itself.

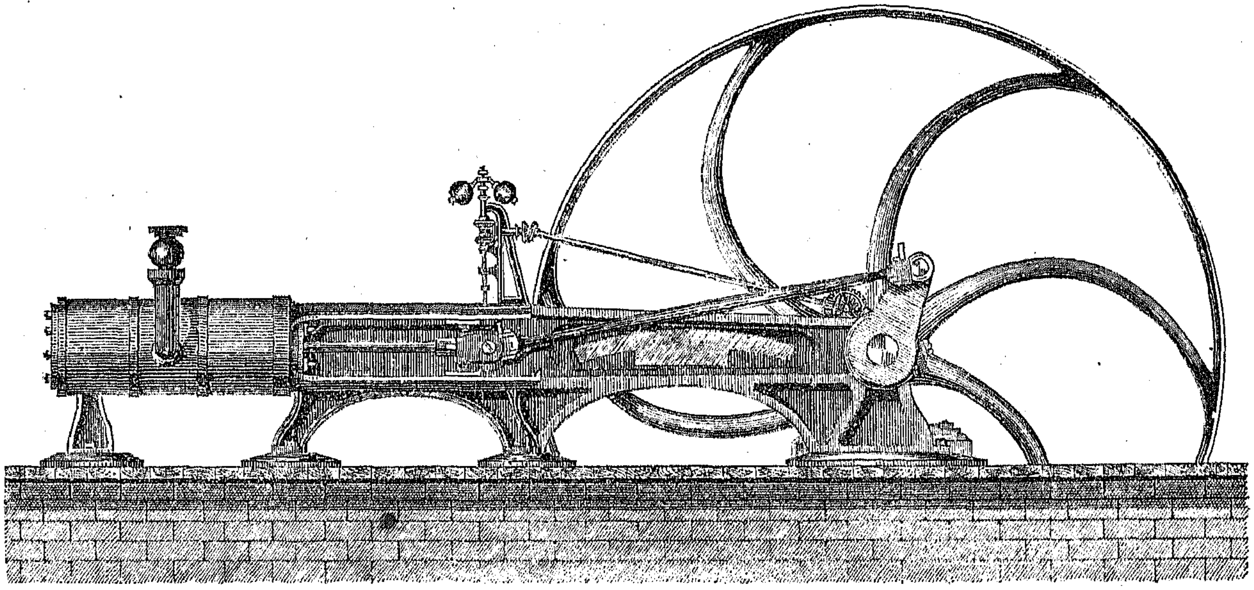

FIG. 14.—NOVELTY IRON WORKS ENGINE.

TYPES OF STATIONARY ENGINES.

Valve-gears.—"The description of an engine naturally commences with the valve-gear and the valves" (Porter), for these are the most distinctive features of an engine.

Nearly all engines employ an eccentric, secured upon the main shaft either flexibly or rigidly, as may be determined by the requirements of the valve-gearing. The eccentric is a well-approved feature. It furnishes large bearing surfaces with small stress, and generally gives little trouble, although it is sometimes caused to heat by the attempt to drive valves of heavy resistance at too high a speed. The action of the eccentric is precisely similar to that of a crank with a radius equal to the eccentricity, and its motion is usually communicated to the valve by means of a strap and rod.

In foreign practice a return crank is often used instead of an eccentric, more rarely here, although the Warren engine (Fig. 17) shows this usage. It brings the steam-chest on the front of the cylinder and permits unlimited length for the main bearing.

It is sometimes desirable to use small eccentrics which cannot be placed upon a large shaft, and an auxiliary shaft is used geared from the main shaft. The object of this is to lighten the valve-gearing and to effect certain motions of closure with a short quick throw. Such auxiliary eccentric shafts are used on some types of Corliss engine and on the type of Cummer automatic engine shown in Fig. 26.

The bearing joint between the eccentric and its strap is usually cylindrical and stepped, having proper grooves for lubrication. In the Buckeye engine the joint is made spherical, so as to be capable of easing and adjusting itself in any direction.

The eccentric is double-acting. Even in the Westinghouse engine, with its claims of single action avoiding the loosening of connections, the eccentric-rod is an exception. In a few cases cams are used in place of eccentrics, or "lay shafts," geared from the main shaft, carry cams, which operate the stems of valves of the poppet type.

In engines of the throttling- or plain slide-valve type the governing principle is not applied to the valve-gearing at all, variations in speed serving only to vary the opening of the throttle-valve in the steam-pipe. Figs. 14, 15, 16, and 17 are illustrations of this type of engine.

A variable cut-off engine is one in which the valve-gearing may be adjusted by hand while the engine is running. The adjustment may be applied to the valves as in Meyer's gear, in which riding cut-off valves moving upon the face of a main valve are changed in position by a right-and-left screw varying the cut-off. In Rider's gear the valve is cylindrical, with admission-edges at such an angle that the cut-off is varied by turning the axis of the valve. A like effect may be obtained with flat valves and inclined port-openings, as is done in the Watertown engine, in which it is used automatically; that is, the cut-off is determined by the position of weights in a governor. Rider's and Meyer's gears are also employed automatically.

Hand adjustment is applied to connecting-links between the eccentric and the valves in many cases, notably in locomotive practice, where it is universal; and in traction, hoisting, and other engines, which may be speeded up to their load with little or no dependence upon centrifugal governors. Hand adjustment may be also applied in varying the cut-off by shifting the eccentric or by altering the throw of the valve through the operation of cams, gears, and levers, as in various devices, some of which are used upon traction engines. In some large compound Corliss engines, the cut-off is made automatic on the high-pressure cylinder with the usual releasing gear, while on the low-pressure cylinder the cut-off is merely set at a given point, which may be readily varied by hand adjustment. In such a usage the bit may be said to be in the mouth of the leading cylinder only, which suffices for the automatic government of the speed of the entire engine.

Automatic valve-gears may be defined as of two types, releasing and positive. These are characterized by several important differences, upon the merits of which there is much discussion. The gears in both types are positive for the main movements of the valve or valves governing the admission and exhaust of steam. The lead, that is, the movement of the valve from its position corresponding to that with the crank on its center to its position when it begins to uncover the steam-port, is usually unchanged. In Corliss engines and in positive cut-off engines with set eccentrics moving a main valve it is unchanged. In an engine such as the Armington and Sims (Fig. 23) the same effect is secured in a combination of two eccentrics, one encircling the other. The lead in all positions of the eccentrics remains constant and practically unchanged. In the Straight Line engine, with what may be called a position eccentric-rod projecting upwards at a slightly variable angle (Fig. 25) from the center line of the engine, the connections are such as to maintain a practically constant lead for all points of cut-off from $\frac{3}{4}$ to 0; this with a single valve and eccentric. In the Porter-Allen engine the tipping motion of the curved link properly adjusted imparts a slight difference of lead at the ends of a cylinder, corresponding nearly with the difference of motion of the piston, due to the angular vibration of the connecting-rod. The Porter-Allen engine either uses a separate eccentric (Fig. 13) for its exhaust-valve or operates both valves with one eccentric, as in the engine shown in Fig. 24.

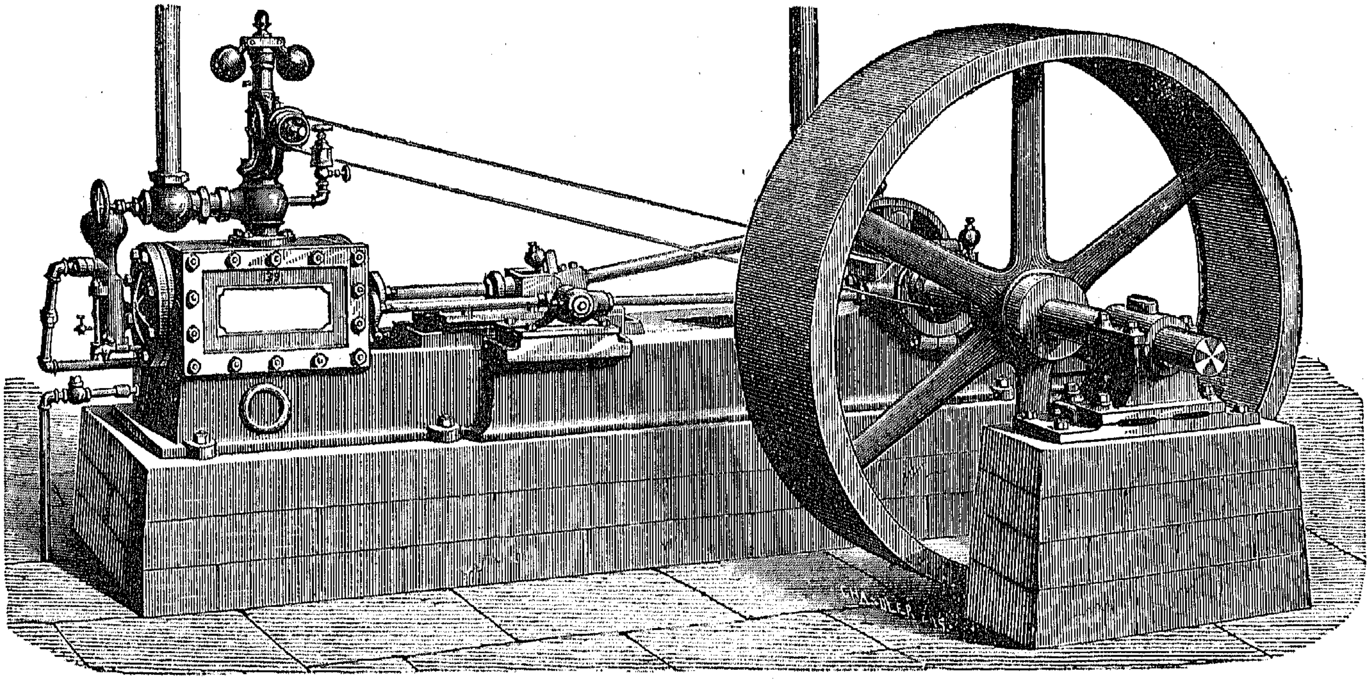

FIG. 15.—ATLAS SLIDE-VALVE ENGINE.

In the positive cut-off engines governing mechanism is applied to shorten or lengthen the throw of the cut-off valves, or to alter their distance apart for the same throw. It is applied in moving a block in a rocking-link in the link-motion engines, and in moving an eccentric in respect to the center of a shaft from which it derives its rotary motion, as is usual in the "shaft-governor" engines. In either case the outcome may be well expressed by using the sailor's term, and saying that we take a reef in the valve travel. The governor is said to be "saddled with actuation," that is, it must vary the cut-off and move the valve-gear under stress. This involves power in the governor, and the power must be derived from the centrifugal force of heavy weights driven in rapid rotation by the engine itself.

But little work is involved in driving these governors. In the shaft-governors the weights operate as so much fly-wheel weight, which long-stroke releasing-gear engines would require in larger proportion. In "actuating" governors the inertia which is acquired conformably with the speed of the engine has only to be changed from time to time by very small increments, so that there is no hesitancy in effecting any change of cut-off that may be required. In the Buckeye governor all the joints are spherical, and kept continuously, though slightly, working by the rapid succession of small resistances. The action of such a governor may be compared with that of a large ball in motion rolling over small inequalities upon the ground. The resistances are there, but they seem overcome with scarcely appreciable effort.

In point of sensitiveness, any effort required by actuation is probably more than compensated by the more frequent opportunities for cut-off afforded by short-stroke engines, and the great power of governors, such as those of the Straight-Line engine and the Ball engine (Fig. 27), is obtainable at no more first or running cost than that of so much fly-wheel.

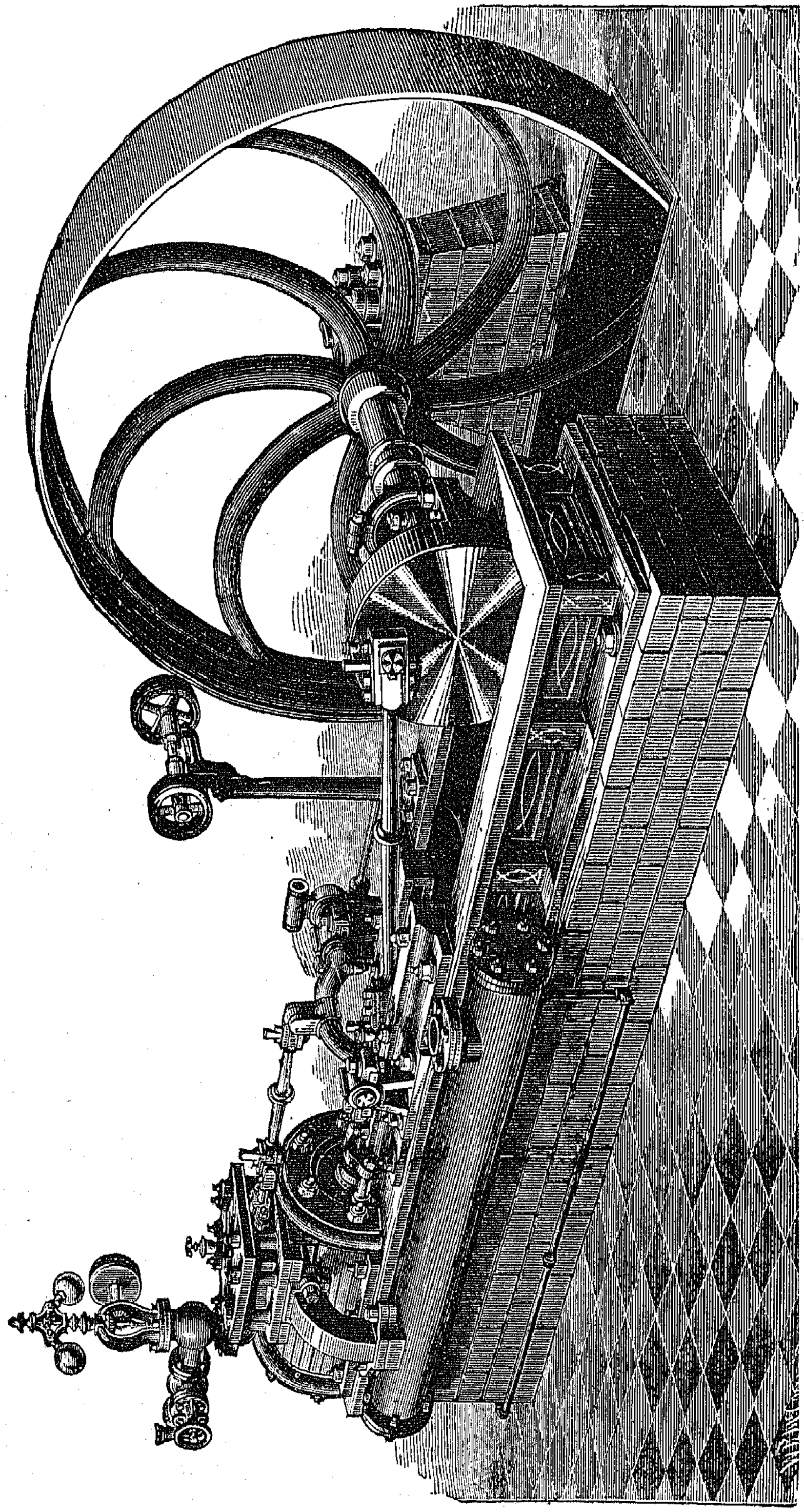

Fig. 16.—Cincinnati Slide-Valve Engine.

In the releasing-gear engines the governing mechanism is applied merely to locate a tripping toe or block, the stress upon which is slight, and in some of the latest improvements in engines of the Corliss type may be said to amount to nothing. It has practically no work to do, and is free to respond with the greatest delicacy to slight pulsations of speed. The movement required for disengagement is slight, but it is sufficient. Hard steel blocks and catches are employed, by which great accuracy and durability are obtainable in these light working parts.

The Corliss principle of release may be applied to flat gridiron- and poppet-valves as well as to the usual taper or cylindrical valves. The details of mechanism employed by builders in this country and abroad are too varied for full consideration here, and we shall confine ourselves to a description of some of the salient features of leading types.

Motion is communicated from the eccentric through rocker-arms (required to sustain the necessary length of eccentric-rod) to a rocking wrist-plate, from which small connecting-rods communicate motion to four (sometimes in case of compound engines to eight) rocking valves. The exhaust-valves have positive connections, as do also the steam-valves for their admission and up to the point of cut-off. Then a toe, usually upon a bushing concentric with the hub of the admission-valve rock-arm, disengages the connection with the wrist-plate. Another arm connects the valve-stem with a rod leading to the piston of a vacuum or spring dash-pot. This has been drawn up by the previous motion, creating a vacuum. The piston now returns to fill this vacuum, rocking the valve backward and effecting a prompt cut-off, as Corliss engine diagrams will generally show. Upon the return movement of the wrist-plate a small spring causes the connecting-rod to the admission-valve rock-arm to re-engage positively, ready for the admission of steam.

George H. Corliss has himself devised numerous modifications of his invention, of which the mammoth engine for the centennial exposition at Philadelphia is a design familiar to many. Of the earlier designs for stationary and factory purposes a well-known arrangement employed a wrist-plate rocking a heavy spring-arm forward of the cylinder. A light curved spring wrapping upon the back of this arm assisted the vacuum-pots in cutting off steam as soon as the point of release was determined by the governor. The type of Corliss gear now in most common use in this country embodies an arrangement substantially of his device, but more favored in practice by others than by himself. This has a wrist-plate in the middle of the cylinder, as shown in Figs. 18, 20, and 31, the engines of other builders. In Fig. 18 the so-called crab-claw of the releasing gear is placed on the end of the connection from the wrist-plate. In Fig. 31, showing a design by Edwin Reynolds, the "crab-claw" depends from an extension of the rocker-arm above the valve-stem.

In the Atlas-Corliss engine the employment of an auxiliary shaft with two eccentrics permits a steam-admission cut-off beyond mid-stroke, at which the range of admission of releasing-gear cut-offs with single eccentrics is limited. In the Wright engine the admission-valves are gridiron slides, but the principle of release is the same.

An "indicating" cut-off gear of an entirely different type is shown in Fig. 32, which illustrates a heavy rolling-mill engine built by E. P. Allis & Co., of Milwaukee, Wisconsin. Its action is thus described by Mr. Hoppin:

> The raising or lowering of the governor-balls moves small valves, which admit water under pressure into one end of a small cylinder and exhaust it from the other end. There is in the cylinder a piston, connected by a rod to the valve mechanism in such manner that the movement of the piston advances or retards the time of closing of the cut-off valves. The cylinder is at all times full of water, and when the engine is at its correct speed the governing valves are all closed, thus locking the piston in position. Any movement of the governor allows water to enter at one end of the cylinder and to escape at the opposite end.

This device is essentially different from the Corliss in that there is no disengagement, and different from most forms of positive cut-off in that the governor does not do the work of shifting the cut off. The valve motion is positive, the connection is unbroken, but water-pressure is called in to do the work.

The method of securing the eccentric is determined by the character of the valve-gear. In throttling-engines, in Corliss automatics and link-motion automatics, and in the main eccentrics of double-eccentric shaft-governor engines, it is made fast to the shaft sometimes by a key, more often by set-screws. The Porter-Allen engine has its eccentric in one piece with the shaft and in the same position as the crank, instead of at right angles to it, as usual. The link is of the Fink type, formed in one piece with the strap, and capable of movement upon rocking trunnions. The main eccentric of the Buckeye engine is secured to the shaft by a wedge-bolt and toothed block, permitting of ready adjustment.

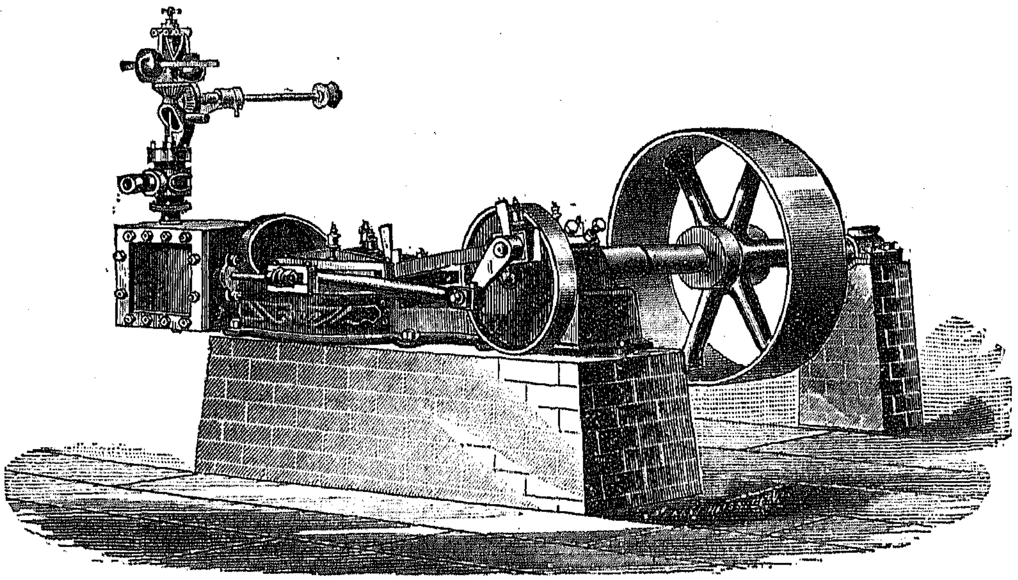

FIG. 17.—WARREN (OHIO) HIGH SPEED ENGINE FOR DIRECT CONNECTED SAW-MILLS.

The loose eccentrics of shaft-governors are most commonly pivoted upon a pulley or disc secured to the shaft. These eccentrics are formed with an elongated eye, through which the shaft passes, permitting a play which furnishes the desired range of cut-off. The throw of the eccentric is so designed that the lead is only slightly changed in the whole range of cut-off, and in some cases causes the valve motion to be "timed with the piston motion, giving a quicker admission for the port at the head end than for that at the crank end of the cylinder." (Joshua Rose on the Ide Engine.) An eccentric merely turned upon its shaft, as is the case with the Buckeye cut-off eccentric, would vary the lead, but with the Buckeye the lead is governed by the main eccentric, and the rocker of the cut-off eccentric-rod is so mounted on the main rocker as to produce a combined cut-off movement, securing quick closure and a travel favorable to uniform wear. The Armington and Sims engine also has an eccentric turning upon its shaft, but here the encircling eccentric compensates in such a way as to preserve uniformity of lead. The devices employed in shaft-governors are very numerous. Instead of the swinging motion upon a pivot some designers employ compound slides, Watt or other parallel motions or traversing-gears, to move the eccentric straight across the shaft, as may be determined by the revolving weights with their controlling springs, which constitute the governor.

Governors.—Of the governors employed in regulating throttling-engines the Judson was a type at one time almost universally used upon small and medium-sized engines. In this a pulley drives a pair of bevel-gears in the yoke of a frame, operating a sleeve-spindle, in an enlargement of which the arms of balls are pivoted. The balls, being thrown outward and upward by revolution, depress a central rod by means of sockets in which the ends of the ball-arms work, and thus close a valve. In the Pickering governor the balls are held by slightly curved springs, and there are no joints. In the Waters governor—a very popular type—the balls are fastened upon curved springs. The Gardiner governor is much used, and the Tabor governor, recently introduced, is more complex in construction, but makes claim to great nicety of regulation. Upon the details of these small governors we will not dwell. They have been perfected by much study and experiment until results have been reached which place the throttling-engine on a much better footing as compared with automatics than it could have held a few years ago. A small engine running under a constant brake load with one of these governors did not vary speed 2 per cent. in a fall of boiler pressure from 100 to 50 pounds. Under 100 pounds steady boiler pressure the load on the brake was increased from 10 to 50 pounds without causing the variation of a revolution, to 100 pounds with a variation of speed of less than 1½ per cent., and to over 300 pounds with a variation of 5 per cent.

Upon large engines the Watt type of revolving pendulum governor is commonly used, being often modified by springs or dash-pots to increase sensitiveness and prevent vibrations. The Porter governor, in which the sensitiveness of regulation is increased by a weight encircling the spindle and not subject to centrifugal action, is very much employed.

In recent years the chief development has been in the introduction of shaft-governors, which have given character to many new types of automatic engines. The weights are commonly hinged upon the arms of pulleys or upon discs secured to the shaft. They revolve in a vertical plane, with a tendency to fly out by centrifugal force which is restrained in part by powerful springs. These are in most cases of spiral form, and subject in some designs to extension, and in others to compression. The forces of weights and springs are unbalanced to an extent necessary to overcome the friction of the valve mechanism, the preponderance being sometimes as much as 10 per cent. in favor of the weights, although it may be made in favor of the springs. The springs are commonly attached to the same hinged-arms to which the weights are secured, and in many designs the initial tension of the springs and their points of attachment may be adjusted to secure the best results. The weights may also be moved so as to alter their leverage and their power relative to the resistance of the spring. With these arrangements it is feasible to secure substantially isochronal government, although this is by no means obtained in many designs. Many of the springs used do not give like increase of stress for different equal increments of extension, and the leverages

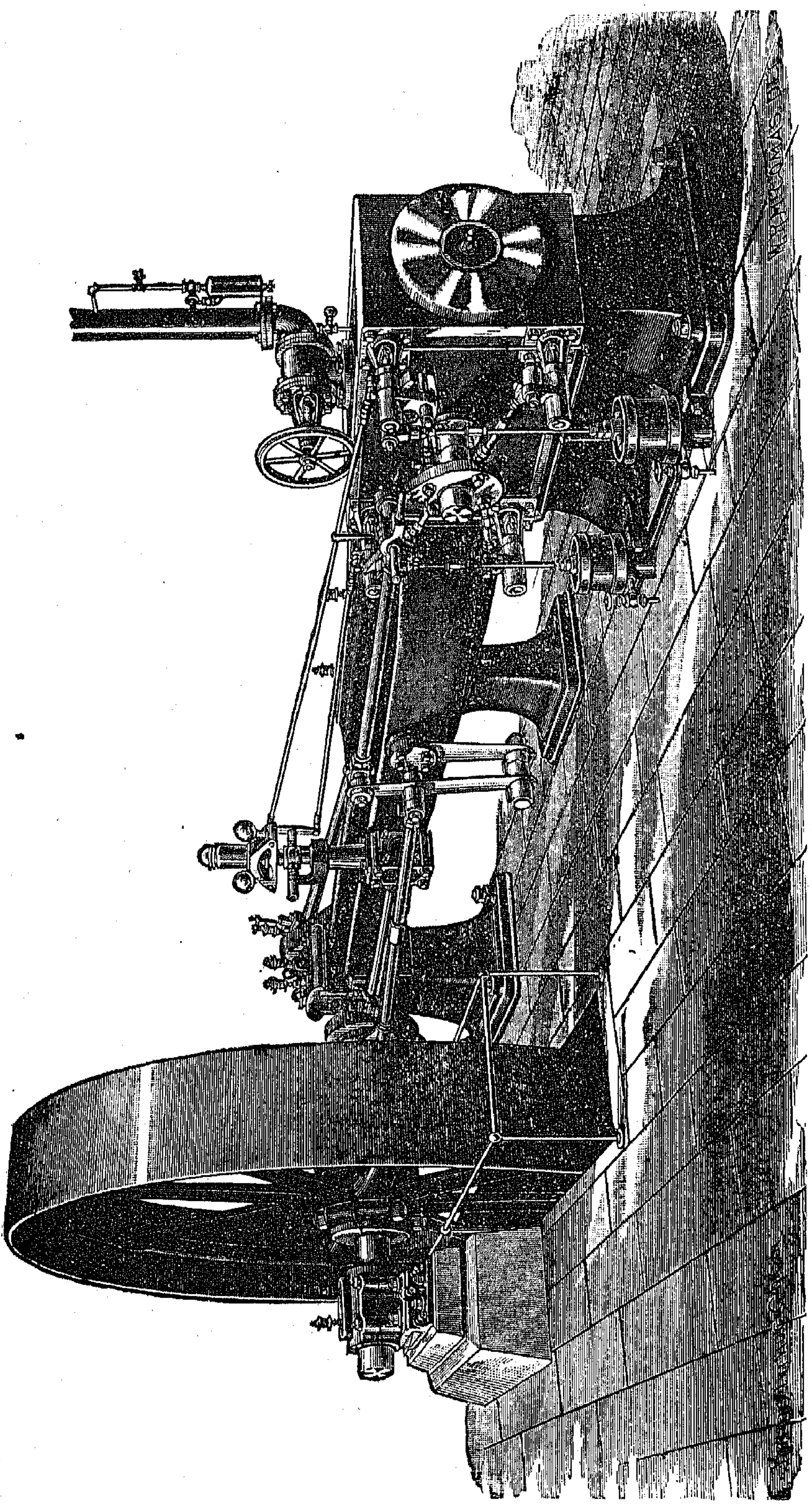

FIG. 18.—CORLISS ENGINE, WITH CAST-IRON FRAME (CINCINNATI, OHIO)

commonly vary for the different positions of the weights. It is feasible to make these variations tie with the variation in the resistance of the cut-off valves for different points of cut-off, and also to cause the engine to speed up under a heavier load.

The methods of conveying motion from the weight-levers to the eccentrics are various. Links are commonly employed attaching to ears upon the eccentric or upon a disk or wing-piece which so gears with the eccentric as to cause its movement around (relatively to the position of the crank) or across the shaft. In one design (Giddings') compound slides are used, which insure a certain degree of stability against vibrations, without which, and with a close balance of weights and springs, there is a tendency to "race". In another design (Ide's) a small dash-pot filled with glycerine secures freedom from these oscillations without sensible impairment of sensitiveness. The use of the dash-pot is to cushion shock and distribute vibration, as oil smooths the surface of troubled water. It is sometimes criticised, but from a purely mechanical standpoint its use is as legitimate as that of a fly-wheel. In another design (Bogert's) the system of weight-connections is made to constitute a Watt parallel motion, the system being balanced by a single spiral spring. In still another (Bigelow's) the flying weights have toe extensions, which operate against the resistance of springs a sliding block to which the eccentric is secured. The block is made to slide upon round rods, and balance is maintained by three springs in equilibrium. In the well-known design of Professor Sweet in the Straight-Line engine a single weight is used, balanced by a powerful spring, which is slightly curved and formed of flatted leaves like an elliptic car-spring. This makes a powerful governor, and is probably the simplest of all, the eccentric being of the pivoted type, and swung across the shaft by an ear attaching to a point of a link which connects the end of the curved spring with the end of the weight-lever.

There is scarcely a mechanical movement which is not capable of application in the arrangements of a shaft-governor, and the efforts of inventors seem to be becoming more and more prolific, and will not be followed at great length. Mr. F. H. Ball is the inventor of a governor in which a new principle of regulation is claimed. A pivoted eccentric is used with the pendulum motion across the shaft, obtained by the movement of a disk which has an internal eccentric ring engaging with a stud in the eccentric. The disk is moved by connection with weights hinged upon the arms of a pulley and balanced by spiral springs secured to the same pulley as is usual. But the pulley is not, as usual, keyed to the shaft, but is mounted free to revolve upon a hub keyed to the shaft with wings or arms connected by springs to the weight-arms pivoted upon the pulley. The pivotal stud on which the eccentric swings is also placed upon one of these wings. The power of the engine is exerted through the shaft, hub, wings, and spring connections, and weight-arms to the pulley upon which runs the driving-belt. The load is the tension upon this belt, and any variation in it acts upon the governing system of weights and springs before the changed resistance taxes or relieves the power which is being exerted by the engine at the previous point of cut-off.

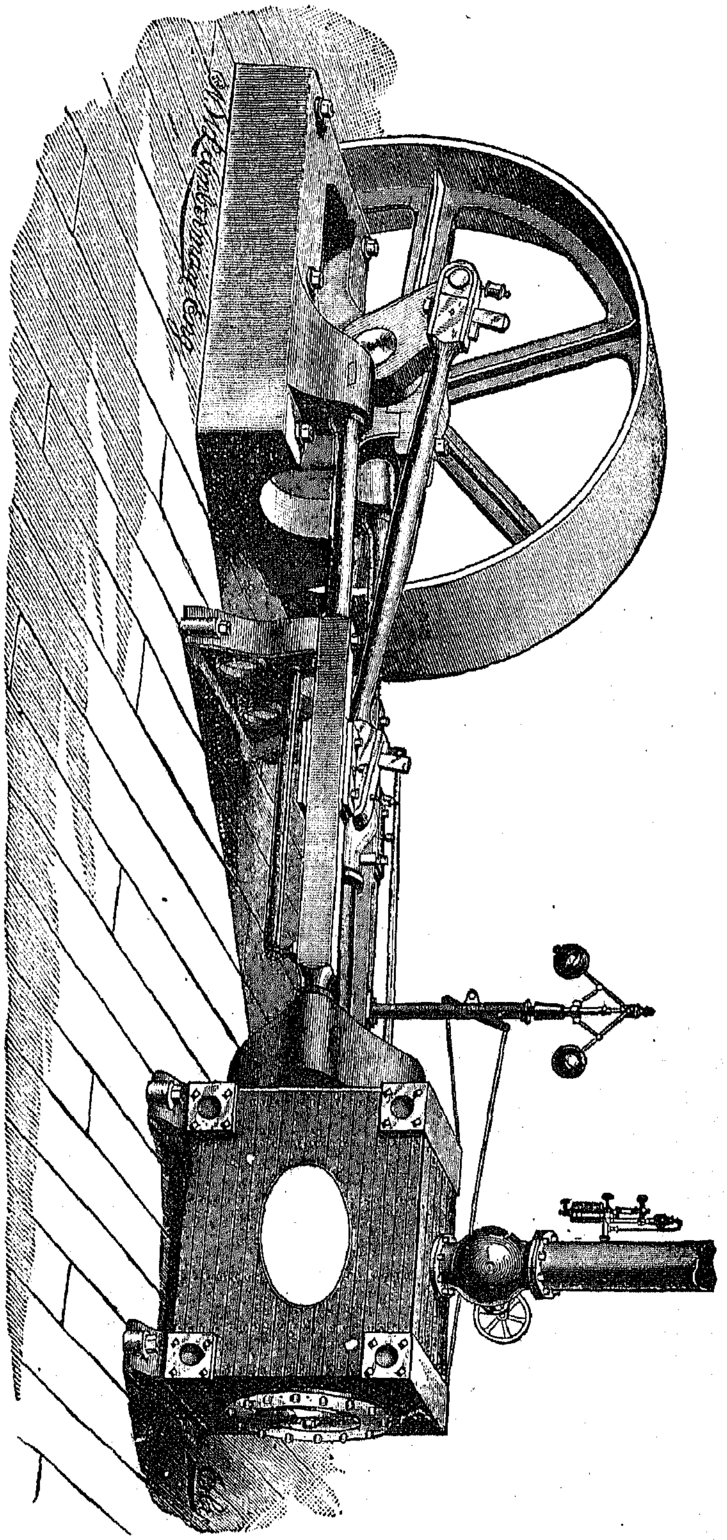

FIG. 19.—CORLISS ENGINE, WITH WROUGHT-IRON FRAME (MILWAUKEE, WISCONSIN).

The power depends upon the regulation of steam supply, and if this depends, as usual, upon variation in speed our premise precludes the possibility of reaching uniformity of speed. This it does not appear to do *in terms* if our steam supply is made to depend upon variation in load, but, in fact, as speed and load are related, variation in load *is* variation in speed so far as the driven mechanism is concerned. Fly-wheels in the power train near the driven mechanism cushion pulsation and secure smoothness of running as well as those upon the engine-shaft. Ordinarily the pulsation due to change of load is gradually taken up by the fly-wheel and gradually felt by the engine in speed and in adjustment of steam supply to meet load with power and restore the former speed by a new equation. In the Ball engine the first draft upon the engine by increased load changes the provision for steam supply *before* the engine speed is retarded in compliance with the unalterable laws of inertia. The action is prompt, the governor may be said to weigh the load, and the practical outcome is a guarantee of less than a revolution variation in speed between an engine running loaded and empty.

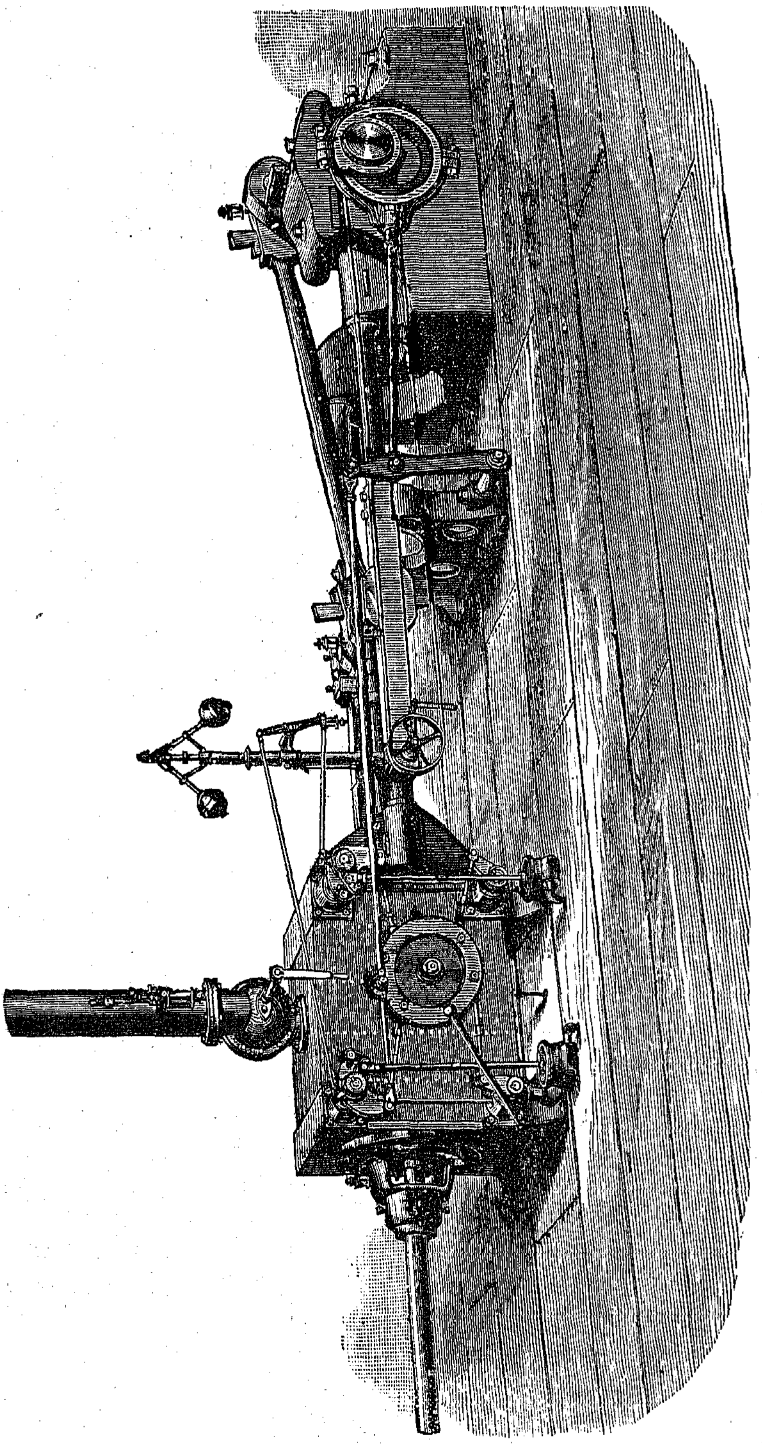

Fig. 20.—Corliss Engine, with Extension-Rod.

But the advantage gained is slight in fact. It is only an advantage in time in a transmission of power which is almost instantaneous. With the Ball engine increased load must do the work of slightly extending the connecting springs, and then the added load, with all its retarding effects, is upon the engine, unless the lost motion gained in the adjusting springs happens at the right instant to extend the impulse of full steam for the stroke of the engine that is taking place, and unless the inertia of the reciprocating parts is overcome before the pulsation of speed reaches the shaft. We have not come to such a refinement as shall smooth the variation of effort during a stroke except in the matter of regulating the inertia of the reciprocating parts, but the advantage of the Ball system of regulation seems to fall within the limits of these variations.

The chief object of a smooth-running engine is to obtain smooth-running machinery. This is done as far as practicable in the best types of automatic engines of various designs. Where shocks and sudden variations arise from the operation of the driven mechanism fly-wheels may absorb these shocks, but the closest obtainable government of engines can not prevent them.

The Cummer governor exhibits the application in shaft-governors of a principle similar to that of the Porter governor among revolving pendulum governors. The sensitiveness is increased by a dead weight acting in conjunction with lighter weights, which only are subject to centrifugal force. The Cummer may thus be said to occupy the position in respect to other shaft-governors which the Porter occupies in respect to the Watt governor. This feature involves some peculiarities of construction, which require an auxiliary eccentric shaft, especially in cases of a coupled or extended main shaft. The revolving weights have links attaching to bell-cranks, by which they are connected to a rod in the hollow center of the shaft. The rod extending out from the end of the shaft connects with a bell-crank rocker, on one arm of which hangs the dead weight, as shown in Fig. 26. A spring also attaches to this arm, and it affords a ready means of adjustment for speed. An engine of this type fully loaded in driving electric lights may have its entire load thrown off at once without any variation of speed that is perceptible to the observer. The best types of high-speed engine, such as the Armington and Sims, the Porter, the Buckeye, the Ball, the Straight Line, the Ide, and others (the variety in meritorious designs is constantly increasing), show similar close results in regulation. With correct adjustments any of these engines are capable of results sufficiently fine to meet any practical requirements even in electric lighting, and some of the most satisfactory plants for electric lighting, especially in the matter of fuel economy, employ large engines of the Corliss type. The employment of a large engine of any type (if the load requires a large engine) is more conducive to economy than the employment of small engines, but the convenience of having a small engine for each dynamo may outweigh considerations of fuel economy.

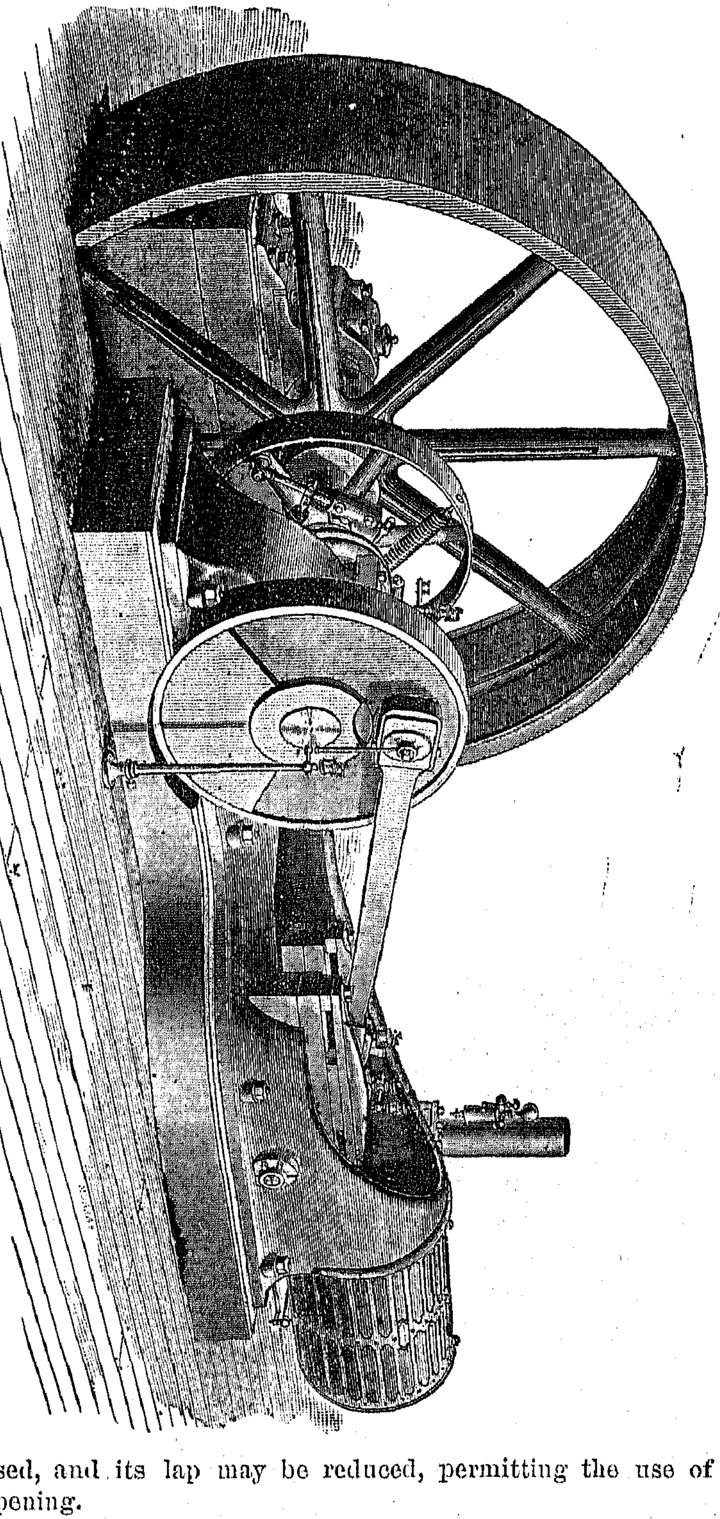

FIG. 21.—BUCKEYE ENGINE WITH TANGYE OR PORTER BED.

Valves.—The poppet-valve of the double-beat type has been described as a perfect valve in theory, opening a large area for a small movement and, if balanced, closing with a touch and without rubbing movement. They are sometimes employed upon stationary engines, but practically the conditions ot high speed increase the difficulties of balancing, and cause a hammering upon the seats, which the use of dash-pots does not perfectly correct. They are therefore not a feature of any leading type of American stationary engine, and the three forms of valves whose employment is most common, and whose merits are most under discussion, are the flat slide, the piston-valve, and the rocking valve.

Whichever of these valves is employed designers have been alive to the importance of securing a large area of admission for a small movement. In sliding valves, whether flat or cylindrical, this end is reached by having two, or four, or more edges of admission. A flat valve, with several slots for multiple admission, is called a gridiron-valve. With piston-valves the number of admission-openings may be increased to any desired extent by using hollow valves slotted through, and working in bushings perforated in a similar manner. The rocking or Corliss valves have usually single admission edges, but the ports are wide and the valve travel is made quick at the point of opening. The arrangement for quick valve travel at certain acting points is a consideration belonging more truly to valve-gearing than to valves, but the quick wrist-motion obtainable in a proper design of Corliss valve-gear makes a single place of admission sufficient. The merit of this feature is recognized by Mr. Porter in the form of "Corliss wrist-motion", introduced into the connections of the admission-valves of the Porter-Allen engine, making a "differential valve movement", by which the opening of the valve is increased, and its lap may be reduced, permitting the use of narrower seats and smaller valves for the same steam-opening.

The wear of Corliss valves is slight, and is compensated in most designs by springs, which hold the acting portion of the valve to its seat. In some engines the valve-stem, instead of passing through the valve from end to end, terminates in a blade or T-head, fitting into a slot in the end of the valve. These rotary valve-stems are packed in various ways, sometimes by regular stuffing-boxes with glands, sometimes by ground joints without stuffing-boxes, a small area under steam pressure keeping all tight. The valves of the Wheelock engine have at one end a hardened steel trunnion and at the other a hardened steel bushing, valves, seats, and bushing-blocks being made tapering one way, and steam being allowed to pass back of the larger end of the valve to hold it to its seat and to take up wear.

In throttling-engines of the old type there is less need of balanced slide-valves, because the pressure of the steam as throttled is reduced. In well-governed throttling-engines proportioned for their loads there is less throttling, and balancing is more important, and in automatic engines with slide-valves some relief from the full pressure on the back of the valve is almost necessary An exception may be noted in favor of the Ball engine, in which the power of the governor is sufficient to actuate plain slide-valves, but even in this the work of moving the valves is to be considered as a cause of wear and a deduction from the power of the engine. The builders of this, as of most other automatic engines, recommend a balanced or relieved valve. A relieved valve is one which we define as partially balanced, enough pressure being permitted to hold the valve properly to its seat.

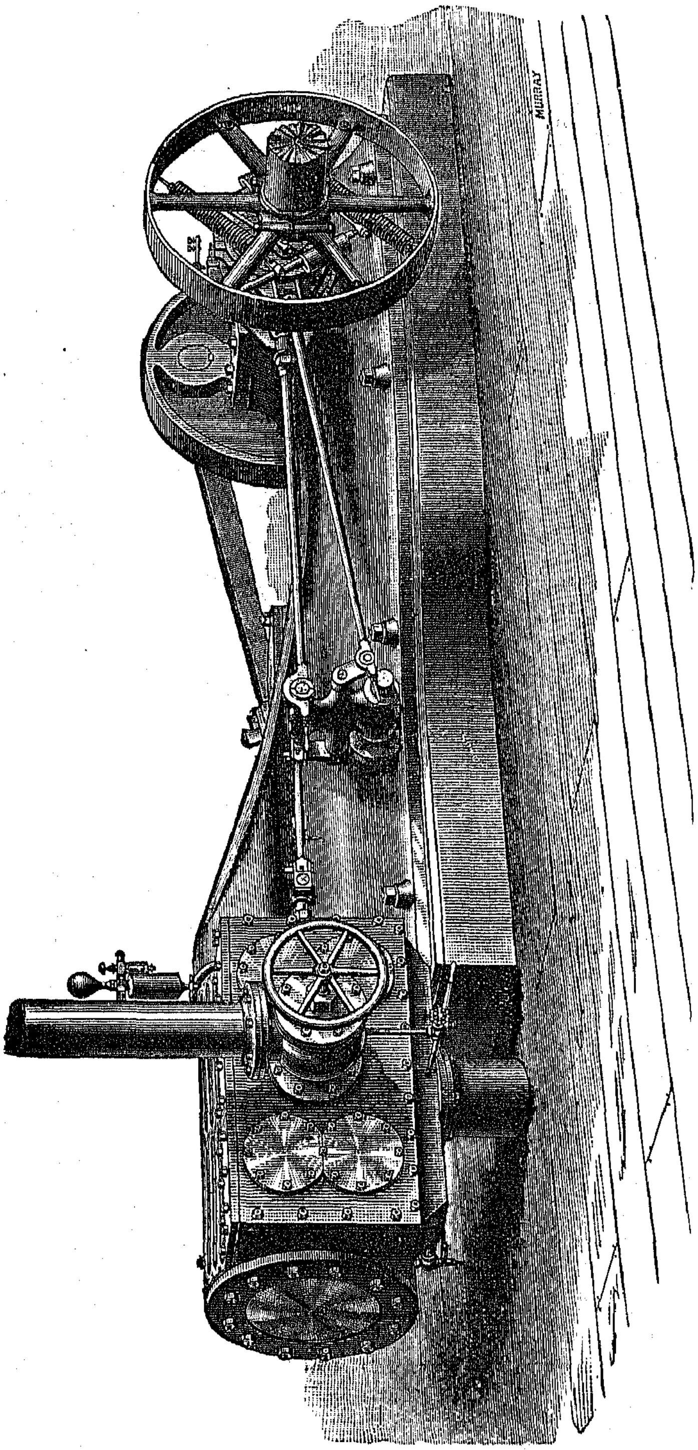

FIG. 22.—BUCKEYE ENGINE WITH TANGYE OR PORTER BED.

Builders of engines having flat valves will naturally refer to the locomotive, in the trying service of which "nothing else has been found to answer". The Porter-Allen engine has flat valves, the admission-valves being separate from the exhaust. The admission-valves have four places for the inlet of steam. The line of draft is central, which is conducive to long wear. Adjustable pressure-plates hold the admission-valves to their seats, being capable of movement on inclines to take up wear and yield for water relief.

The valve of the Straight-Line engine is a rectangular iron plate, with a back plate and side strips, in which, as a framing, the valve moves "practically frictionless". The back plate permits of compensation for wear and yields in case of water in the cylinder.

The Ball engine has a flat valve in two parts, between which is a packed piston. The arrangement partially relieves the pressure on the back of the valve and permits of automatic adjustment for wear. The valve-seat is rescraped during the testing of the engine until there is no leakage under full boiler pressure.

The Cummer engine has a flat main valve with a flat riding valve. These are small valves, with short movements, and the designers prefer such valves unbalanced to the complexity involved in balancing arrangements, relying upon the power of their governor to handle the valves easily, as it appears to do.

The Buckeye valve is peculiar in many respects. It is a relieved valve with a riding cut-off, and its success is attested by long usage. The main valve is of a box type, the interior of which is supplied with steam through open pistons, furnishing pressure areas, by which the valve is held to its seat. The cut-off valves are light plates working inside of the box-valve. Their stem works through the hollow stem of the main valve. To secure a nearer approach to a balance steam is admitted and exhausted from relief chambers in the valve-seat. The engine may be run with steam-chest covers off, and the tightness of the valves may be assured by inspection under steam.

The exhaust-valves of the Porter-Allen engine are self-tightening by steam pressure from the cylinder acting on a copper diaphragm, which holds the valves to their seats by a frame attaching to the diaphragm. This device is the invention of C. B. Richards.

The piston-valve furnishes the nearest possible approach to an absolutely balanced valve. It moves with little friction, and for its size and weight may be made to open larger admission areas than any other type. It is easily handled by shaft-governors, and has been adopted by many builders of engines so governed—the Westinghouse, the Ide, the Armington and Sims, the Beckett and McDowell, and numerous others. It is employed in the large rolling-mill engine shown in Fig. 32, which has separate valves for admission and exhaust. These valves are liable to wear leaky, the hole, as is said, wearing larger and the valve smaller, but the valve has no less proved itself a practical working success. Some builders use packing-rings to maintain the tightness of the valves. These are employed in the Westinghouse valve, as shown in Fig. 30. The Beckett and McDowell engine uses Baxter's piston-valve, in which a wide bearing-ring may be set out uniformly by means of a follower with bolts drawing up circular and concentric wedges. The valve used in the Armington and Sims engine has no packing-rings nor adjustments for wear. It works in a bushing, which, like the valve, is replaceable at slight expense, and both are so finished and hardened to endure wear that they will last without leakage for years, such valves having been found to be perfectly tight after over 10 years of use.

Piston-valves and some types of balanced valves make no provision in themselves for the relief of water in the cylinder. To provide for this contingency the Ide engine employs diaphragm-caps screwed upon the cylinder, the diaphragms bursting before a dangerous pressure is reached. The Westinghouse engine employs a replaceable pop-out head set into the cylinder-head. In other engines pop-out plugs or water-relief cocks closing by springs are employed for the same purpose.

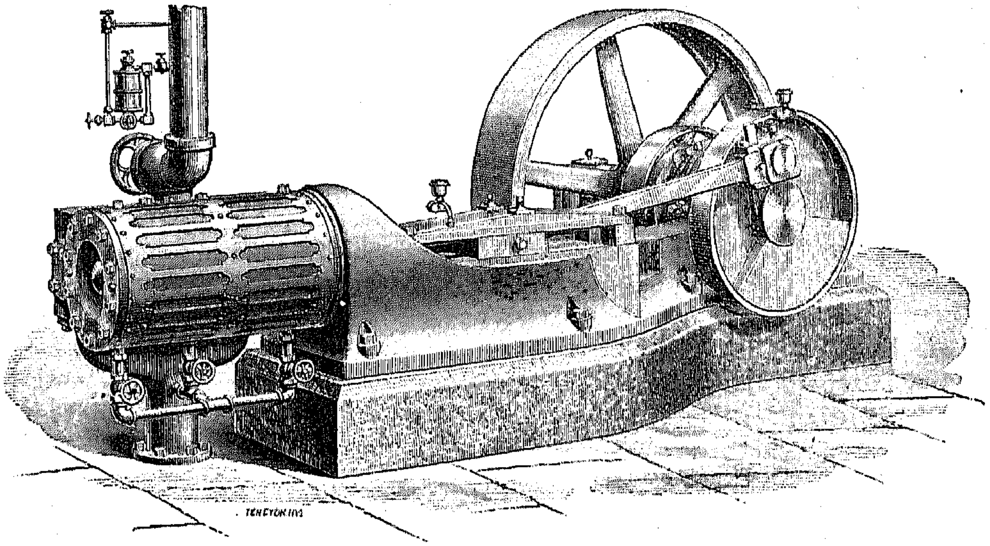

FIG. 23.—ARMINGTON AND SIMS ENGINE.

Frames.—If the valve-gearing embodies the most essential differences in the working organism of engines, the frame may be considered "the backbone of the engine," and gives it a characteristic appearance. Most large and long-stroke horizontal engines have modifications of the girder-frame. One of the earliest examples of this is shown in Fig. 14, the design of Horatio Allen. The framing is based on scientific principles and exhibits in its form the distribution of strains and the economical disposition of the material. The spreading web-footed stands, the curving bridge-like contour of the girder-spans, the stiff support under the guides, and the termination of main framing at the front cylinder-head, these may have some appearance of oddity to eyes familiar with later designs, but they are more correct than many of them. The comparatively slight support necessary for the cylinder is shown in the light stand, but for which this part of the engine would overhang. In Fig. 18 is shown a Corliss engine with cast-iron girder-frame. This is an ordinary style of framing, but of more than ordinarily graceful design. The stout post or foot supporting the end of the cross-head ways is a feature to be approved for rigidity in so long a girder, although it may be dispensed with in a shorter girder, as shown in Fig. 26.

In Figs. 19 and 20 wrought-iron frames are shown. The overhung-crank engine may be considered a one-sided construction, the strength of the frame being on one side of the main line of exertion of power, for which reason it has to be made the heavier. But in the construction shown the pillow-block support is extended in a large box-frame of cast-iron with heavy bosses for wrought-iron stretchers, extending to similar bosses on the cylinder-head and keyed at both ends. The resultant resistance to draft is central, and the stretchers are squared to serve as slideways for the cross-head.

In Fig. 32 we have an example of a cast-iron frame for heavy service, the usual girder being brought to the base in one continuous flanged foot.

The Straight-Line engine (Fig. 25) is a center-crank engine, deriving its name from the framing, which "runs in straight lines from the cylinder to the main bearings and exactly central with the line of strain, the frame resting on three self-adjusting supports, thus securing a constant true alignment".

Most of the early types of throttling-engines used a substantial framing, of which Fig. 16 is a good illustration. It may be called a box-frame. With sufficient weight of iron it is a good framing, steady, and with resultant resistance to draft central, but lacking beauty of outline, and not economical in its disposition of material. Fig. 15

shows a modification of this type, conforming more to the plan of the engine, but still with a solid box support under the cylinder. This engine had a very large sale at a time when a frame permitting the cylinder to overhang would have met with no favor.

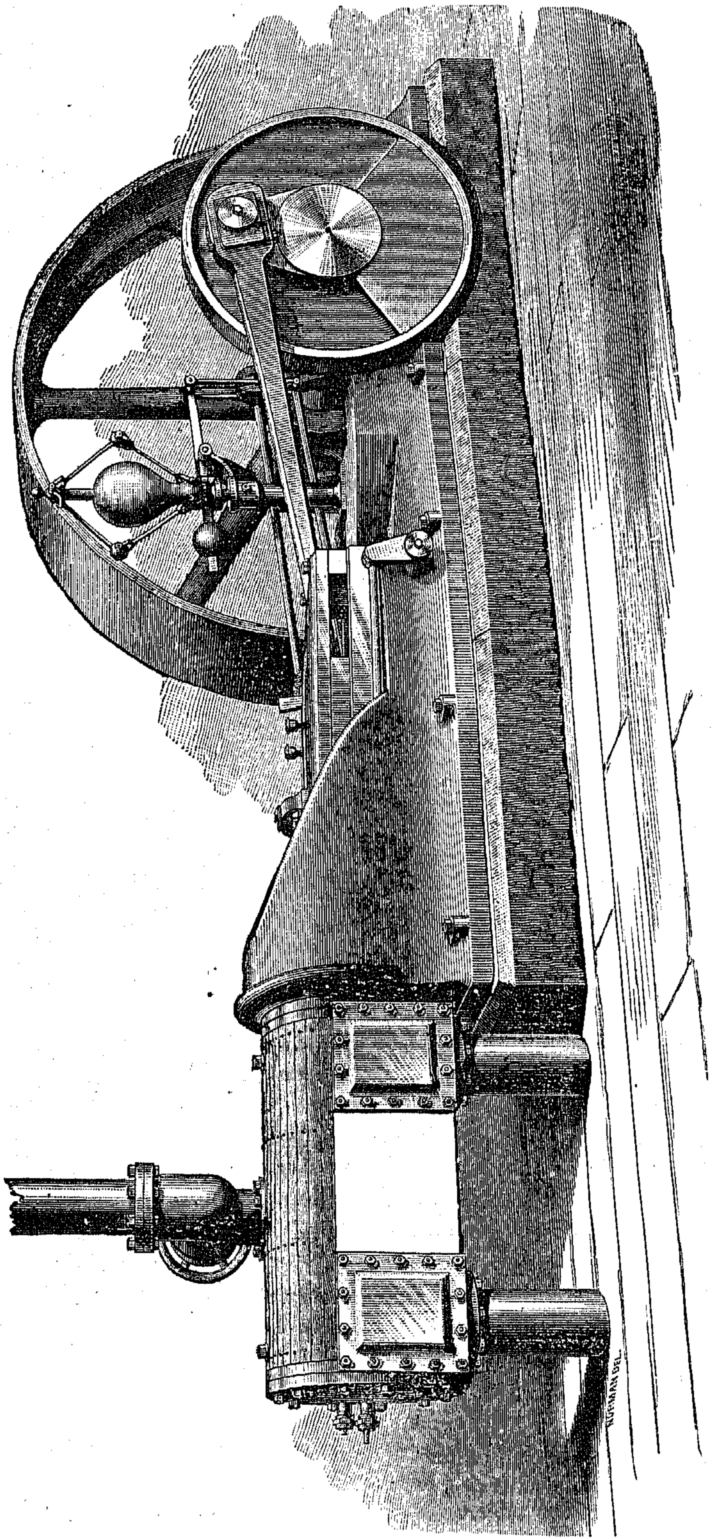

Fig. 24.—Porter-Allen Engine.

For short-stroke engines, throttling and automatic, the Porter bed is the type coming into most general use. This is sometimes called the molded-rim bed, from the base being in one continuous rim from which the body of the frame ascends in gracefully-molded contour, but it is more often called the Tangye bed, from the English manufacturer, who followed the design exhibited by Mr. Porter at the Paris exposition (1867). The name is commonly used perhaps because it has a certain tang of foreign flavor, but the merit of the design belongs to Mr. Porter. Figs. 17, 21, 22, 23, 24, and 27 show engines with Porter beds. These frames are usually well stiffened with interior cross and longitudinal ribs, and the material is disposed so as to take the stresses and form a substantial base for the portion of the frame on which these stresses come. The cylinder is left to overhang, having only its own weight to support, which is little in comparison with the power exerted between the piston and the crank.

The Westinghouse engine, shown in Figs. 28, 29, and 30, is a peculiar type of vertical trunk engine, having an inclosed frame covering all the bearings, which are constantly bathed in a lubricating mixture of black West Virginia oil and water. The protection of bearings is particularly necessary in the surroundings of dust and grit under which engines are obliged to work in some manufactures. Watches have dust-proof cases, and the bearings of engines would often show better service if it were practicable to apply any such protection. The high speeds at which the Westinghouse engine easily works may be explained in part by the ample provisions for cooling the bearings, and the further progress of high speed may be thought to depend upon better facilities for lubricating, cooling, and even refrigerating the bearings, such as inclosing frames may permit us to employ.

Bearings.—In some cases the main bearing is capped at an inclined angle, but the best prevailing practice is to use four-part boxes, the caps horizontal, and the cheek-pieces adjustable by wedges and screws. A rigid support is obtained by making the bearing in a massive jaw in the bed, and giving broad surfaces to the cheek-pieces and adjusting wedges. In the Porter-Allen engine these wedges are located on either side at the edges of the bearings: so as to secure the greatest rigidity of support for the crank shaft, the forces applied to which tend to deflect it.

In a main bearing provision has to be made for the resistance of forces and for wear in at least three directions: horizontally either way and vertically downward. The horizontal forces being greater than those due to gravity, the cap is sometimes placed vertically at the end of the bed to supply the greater adjustment. Great rigidity is, however, secured by bedding the bearing with substantial cheek-pieces in a solid uplooking jaw of the frame, and the adjustment for wear meets every practical requirement. In girder-frames, with slideways for vertical cross-heads, the top of the girder is brought much higher than the center of the shaft, as appears in Figs. 18 and 26. This permits and almost requires for good appearance a very deep and rigid cap, large enough to furnish a reservoir for lubrication.

Brass boxes are sometimes used, but the use of babbitt is much more general and in every way satisfactory, if the metal be made from tin, antimony, and copper in correct proportions.

The main bearings of the Westinghouse engine are not made with boxes capped in the usual fashion, but sleeve-shells are used, babbitted, and firmly secured by taper sleeves and bolts. These shells are replaceable for wear, or may be rebabbitted. The method of making these babbitt linings is thus described:

> It was at first our practice to bore and ream the babbitt lining to an exact fit on the taper. Experience has, however, demonstrated that better results are obtained by retaining the natural skin or surface of the babbitt metal, which is found to have better anti-friction and wearing qualities than the softer metal beneath. But a lining of babbitt, which is simply poured around a mandrel, owing to shrinkage, may become loose in the box, and from the same cause may fail to show a fair bearing surface. To insure a hard, solid, and perfectly true bearing, the metal is poured around a mandrel, which is a little smaller than the shaft. When set, a taper steel mandrel, which is ground exactly true to the full size, is forced into the bearing up to a shoulder by a hydraulic press, which yields a net pressure of about 15 *tons to every square inch of the surface of the babbitt.* The shell being held in by a massive chucking ring, the metal is thus expanded into it with enormous force. Nothing can exceed the beauty and absolute truth of a bearing surface so obtained, and we feel justified in regarding it a mechanical process of great elegance.

The slide-bearings, forming the cross-head ways, depend in form upon the type of cross-head. For vertical cross-heads, commonly used with girder-frames, and of a height permitting the oscillation of the connecting-rod between the webs which support their ways, the bearings are sometimes bored out, but are more often flat slides, or slides converging at an obtuse angle for purposes of lubrication. Flat slides, with proper channels, seem to furnish every requisite for good lubrication and enduring service. Replaceable steel strips are sometimes used, but hard, fine-grained cast-iron is very durable, and can hardly be bettered by steel. Frames are sometimes cast of iron which is very strong but porous, so that the guides planed in the metal show a surface which wears out cross-head shoes very rapidly. In such a case strips of steel or of smooth cast-iron are almost necessary.

For high-speed engines the locomotive type of cross-head, with its flat bar guides, is commonly employed, and in point of durability nothing more could be desired.

The power-train.—The moving parts, through which the pressure and work of steam is transmitted to the main shaft, may be defined as the power-train, comprising in most steam-engines approved by large usage several standard parts: the piston with its rod, the cross-head, the connecting-rod, and the crank.

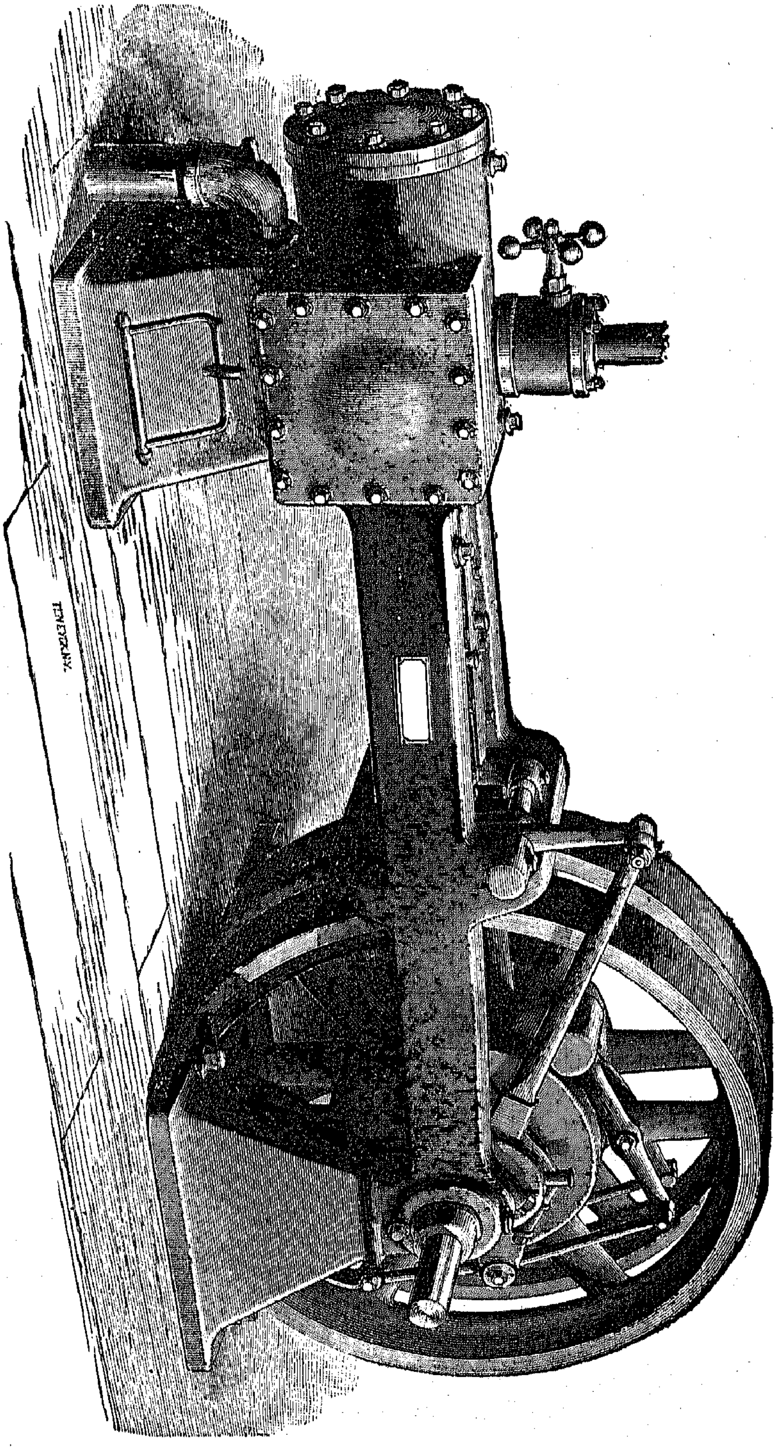

FIG. 25.—STRAIGHT-LINE ENGINE.

In pistons the tendency seems to be in the direction of liberal depth and simplicity in packing. Long-stroke engines commonly employ some form of jointed segmental rings pressed out by springs, of which there are a number of approved types, the Babbitt and Harris packing being largely used. With the high-speed engines, small snap-rings are almost universally used, as in the Porter-Allen, the Straight-Line, the Westinghouse, the Armington and Sims, the Ball, and other engines. In the Westinghouse engine, as is usual in trunk-engines, the piston, serving also as a cross-head, is made of extra depth, to provide sufficient bearing-surface. In the pistons of long-stroke engines followers are used, but the high-speed engines have usually pistons that are solid or cored out hollow and plugged after removal of the core.

The standard method of securing piston-rods in the pistons is by means of a taper fit, terminated with a screw and nut. In some engines the rod is screwed and shrunk into the piston.

In considering the cross-head we are first brought to the question of equalization of effort upon the crank-pin by giving weight to the reciprocating parts, chiefly the cross-head and the piston. Two entirely different principles of design prevail, of which, in this respect, the Porter-Allen engine and the Straight-Line engine may be considered representative types. Referring to the Porter-Allen engine, we quote: "No amount of testimony", said Mr. John Hick, then the leading builder of stationary steam-engines in England, after he had come every day for a fortnight and watched one of these engines in the Paris exposition of 1867 running with 24-inch stroke at 200 revolutions per minute—"no amount of testimony would have made me believe that a steam-engine could be made to run at that speed with such absolute smoothness". "The secret of it", adds Mr. Porter, "was the inertia of the reciprocating parts between the steam and the crank".

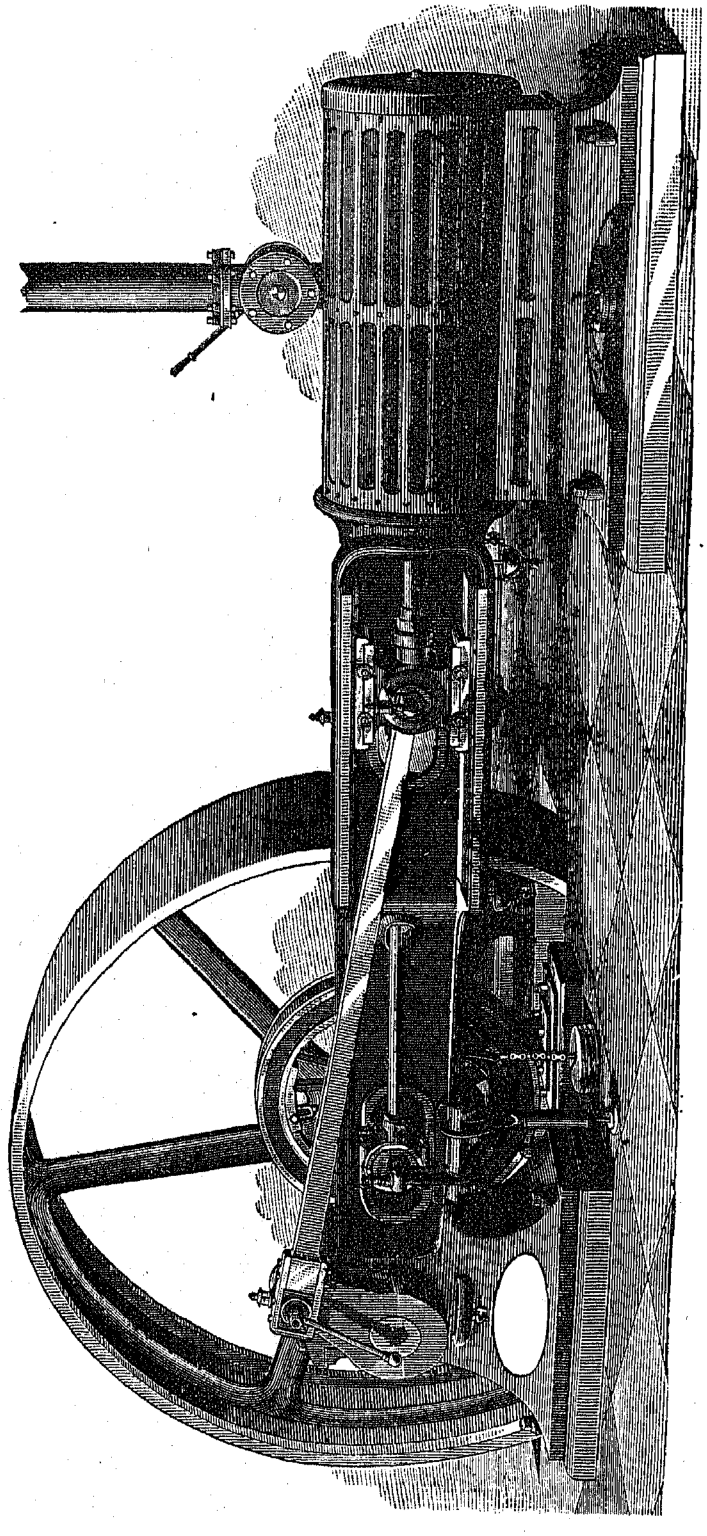

Fig. 26.—Cummer Engine.

This is explained as follows: At the beginning of the stroke of an engine there is full pressure of steam on the piston. This pressure has to meet the continuous resistance of the work upon the engine. It has also to overcome the inertia of the reciprocating parts, which must be brought from rest to the speed of the crank-pin between the beginning and the middle of the stroke. When mid-stroke is reached, the steam having been cut off, the pressure of steam in the cylinder has fallen by expansion, and as this pressure continues to decrease, the reciprocating parts, in slowing from the speed of the crank-pin to no speed at the other dead-center, by their inertia exert a pressure which helps the decreased steam pressure. By making the reciprocating parts of such a weight that their initial acceleration requires a pressure about half that of the initial steam pressure, the effort at the crank is made nearly uniform throughout the stroke.

The facts of the action of inertia are unquestioned, but the desirability of producing a uniform effort upon the crank-pin throughout the stroke does not meet with universal concurrence. Engines which are constructed with the reciprocating parts as light as consistent with durability and strength are run with great smoothness at high speeds, and not a few builders, even some who mention the virtue of a "reciprocating fly-wheel" in their advertisements, in design take a middle ground, giving the parts a weight with which the uniformity of effort obtainable is only partially realized. The beneficial effect of inertia in the reciprocating parts in the earlier part of the stroke is supplemented in the latter part by a suitable compression, which cushions the effort upon the crank-pin down to little or nothing as it approaches its dead center. The maximum effort upon the crank-pin may be much reduced by properly loading the reciprocating parts.

The practical outcome of the advantages described may be overrated, for, on the other hand, we have light parts working with less friction. The variations in successively reversed impulses have less to do with smooth running than the fact of high rotative speed itself, which not only greatly increases the regulating power of the fly-wheel, but secures uniformity, by substituting for a few long and heavy impulses, in the same time, a great number of short and light impulses. As this subdivision increases, the character of the strokes in respect to the graduations of effort during their brief continuance becomes of less and less moment.

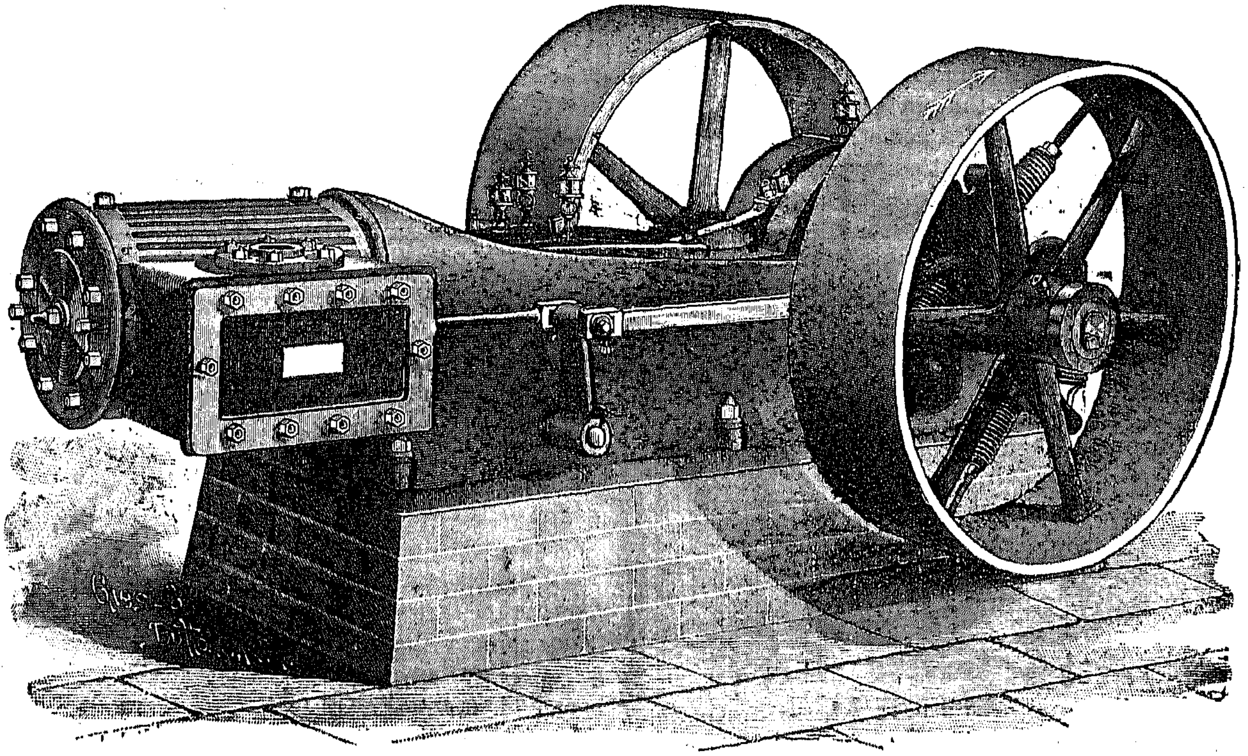

Fig. 27.—Ball Engine.

Cross-heads are chiefly of three types: the vertical, having bearing-surfaces above and below a central eye; the slipper, having a bearing-surface below the eye of the cross-head pin; and the horizontal or locomotive type, having double bearings on either side, with the eye of the cross-head pin in the middle. Those most commonly in use are the vertical cross-heads for girder-beds and the locomotive type of cross-head for Porter beds. The vertical cross-heads are either turned or planed, and are usually provided with means of adjustment by screws and set-nuts, or by wedges with screws and set-nuts. The wear is very slow. In the Ide engine the only compensation thought necessary may be obtained by laying a thin strip of paper or metal between the body of the cross-head and the lower shoe.

Equilibrium valves of the rectangular piston type will wear more or less variably from steam flow or other causes, but cast-iron cross-heads of the locomotive type, with large bearing-surfaces and kept clean (though similar in form), are said never to wear. This may not be absolute, but there are engines which have been running for a quarter of a century which are declared to have had no adjustment of such wearing-surfaces. An engine with running-gear of the type shown in Fig. 17 has been in active service over 16 years with "no wear at all", that is, no appreciable wear, upon the sliding surfaces, and the cross-head travel at high speed has covered a prodigious distance in this time. In the Porter-Allen and other engines using this type of cross-head it is not thought necessary to provide any adjustment for wear.

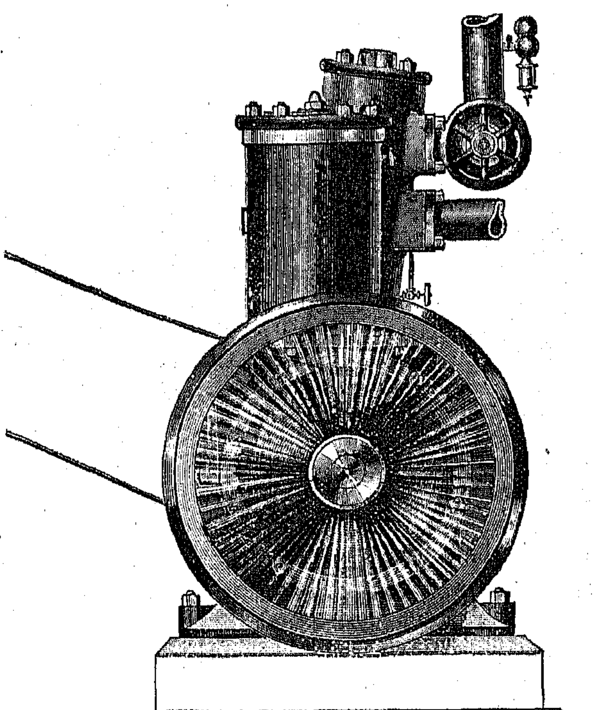

Fig. 28.—Westinghouse Engine.

The lubrication of cross-heads is accomplished by the use of oil-cups upon the upper guides, with ways for carrying the lubricant from the upper to the lower sliding surfaces and distributing it upon both. The oiling of the pin may be accomplished in the same way, or a separate oil-cup may be used, reciprocating with the cross-head or mounted upon the head of the connecting-rod. Continuous oiling from a stationary cup is secured by the use of wipers, which pass a drop of lubricant at every stroke.

The standard method of securing the piston-rod in the cross-head is by means of a key, but a screw with set-nut is not unfrequently used, and the Buckeye and Straight-Line engines have peculiar methods of securing the rod. In the Buckeye the cross-head (of the vertical type) is in halves, which are pinched upon the thread of the piston-rod by bolts. The construction is neat and safe, hiding the thread, and requiring no set-nut. In the Straight-Line engine two sides of the rod and two sides of the nut in the cross-head are slabbed off, so that a quarter turn will release the rod after removing two clamp-bolts, which pass close to its flattened sides and hold it securely in place.

The cross-head pin is generally placed in the center of the length of the cross-head, to avoid any tendency to spring the piston-rod. The pin is commonly fixed in the cross-head and is a center-pin, upon which the end bearing of the connecting-rod turns. The Straight-Line engine is peculiar in having the pin-bearings with adjustable boxes in the cross-head, the pin being fixed in the end of the rod, and a modified design dispenses with these boxes by making the adjustment in the pin itself, in which the bearing sides may be spread apart by taper wedges operated by bolts. Cross-head pins are sometimes turned solid, but are more often of steel let into the cast-iron head and secured by bolts. They are flatted top and bottom, the wear coming upon the sides. The Ide engine is exceptional in using a round pin, which may be turned to equalize wear. This is secured by a split taper sleeve and screw and nut on one side drawing up against a taper of the pin in the opposite cheek of the cross-head.

The standard form of connecting-rod end is that in which brass boxes are secured by a steel strap with gib and key and set-screw. In other types the stress is taken by bolts with a key for adjusting the boxes. A type in growing favor is styled the "solid end" rod, in which no strap is used, the brass boxes being let into an opening in the head of the rod, with adjustment by broad flat wedges held in position by screws or by through-bolts.

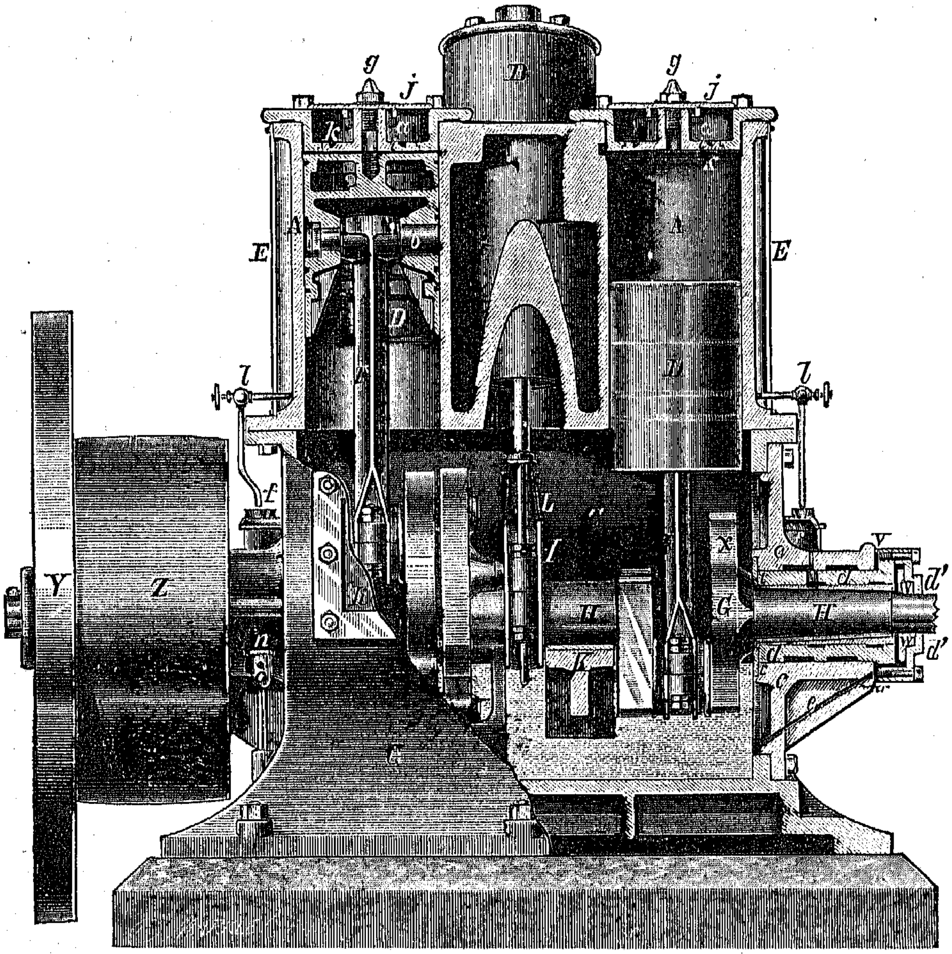

FIG. 29.—WESTINGHOUSE ENGINE, SECTION THROUGH CYLINDERS.

The greater vibration at the crank end of the rod increases any liability to loosen a key at that end. We therefore often find the usual strap, gib, and key at the cross-head end, while at the crank end the solid type with wedge is used, or the marine type, in which a bearing-cap is bolted down over the half boxes of the pin endwise.

Where keys or wedges are used at either end of the connecting-rod they are so placed that the wear of boxes at one end will compensate for that at the other and preserve the length of connection nearly unchanged. Single action, as in the case of the Westinghouse engine, avoids the reversal of stresses. This requires ordinary connecting-rods to be carefully keyed up, heating resulting if the boxes are set too tightly and pounding if they are left at all loose.

The connecting-rods of American engines are usually of liberal length, being commonly more than five and often six or more cranks long, so that the stresses upon the guides are reduced. The ratio of connecting-rod to crank does not average as high in foreign engines. In the Westinghouse engine another advantage of single action is realized in offsetting the shaft from the center line of cylinder, so that the angular vibration of the rod is greatly reduced while under stress from the steam pressure, which acts only on one side. This is tantamount to using a connecting-rod about ten cranks long without taking up the space which would be occupied by such a connection.

In large stationary engines a usual method of proportioning the crank-shaft bearings is to make them of a diameter equal to half the diameter of the cylinder and of a length equal to the diameter of the cylinder. Increased stiffness is commonly secured by giving the shaft a greater diameter between bearings. As engines are speeded higher the overhang of the crank-arm and pin become proportions which it is desirable to reduce as far as possible. The crank-pin may be made larger and shorter, and the crank itself may spread into a counterbalanced disk, as in the Porter-Allen engine. The plain disk-crank is used in many engines, especially in plain slide-valve engines running at high speeds, but in the automatic engines of low rotative speed the ordinary single crank is used. For high speeds there is only one step beyond the disk, and that is the double crank or the double disk. This we see in one form of the Armington and Sims engine, and it is also a feature of the Straight-Line engine, in which the cranks are made to play the part of fly-wheels.

Crank-pins are variously secured: by bolting, shrinking, or riveting, and cranks are commonly keyed upon their shafts. An ingenious method of centrifugal oiling was first introduced as a feature of the Buckeye engine. A hole is drilled lengthwise of the crank-pin and a smaller one radially outwards to the bearing. A tube extends from the former hole to the center of rotation, and oil delivered into a stationary ball at the end of the tube is carried by centrifugal force to the crank-pin bearing. In the Straight-Line engine a centrifugal feed is also used, the oil being delivered into an annular recess in the crank-hub, from which it is carried to the pin. In the Porter-Allen engine stationary lubricators are used, all moving parts being lubricated by wipers without the use of wicks. Reference has already been made to the inclosure of working parts in a lubricating-reservoir as employed in the Westinghouse engine.

In packing piston-rods and valve-stems there is substantially no variation in the usage of flexible packing material set up by glands except in the case of the Straight-Line engine, in which the piston-rod is ground and works through a reamed hole in a very long bushing of compressed babbitt "without contact and steam-tight". The bushing is spring supported and free to move, and the valve-stem is also ground and works in a long babbitt bushing, the aim of the designer being to produce an engine which should require no packing.

Evidence of design.—Before leaving the consideration of engine details, which might be dwelt upon at much greater length, it is worthy of remark that the novel features introduced in American practice are more than simply ingenious. They show a distinct avoidance of complexity and a careful adaptation of the means to the end. The most radical departures from previous practice are found to be based on the conclusions developed from the study of scientific principles, and they have been pushed to success in opposition to a great deal of prejudice based on the pre-existing condition of things.

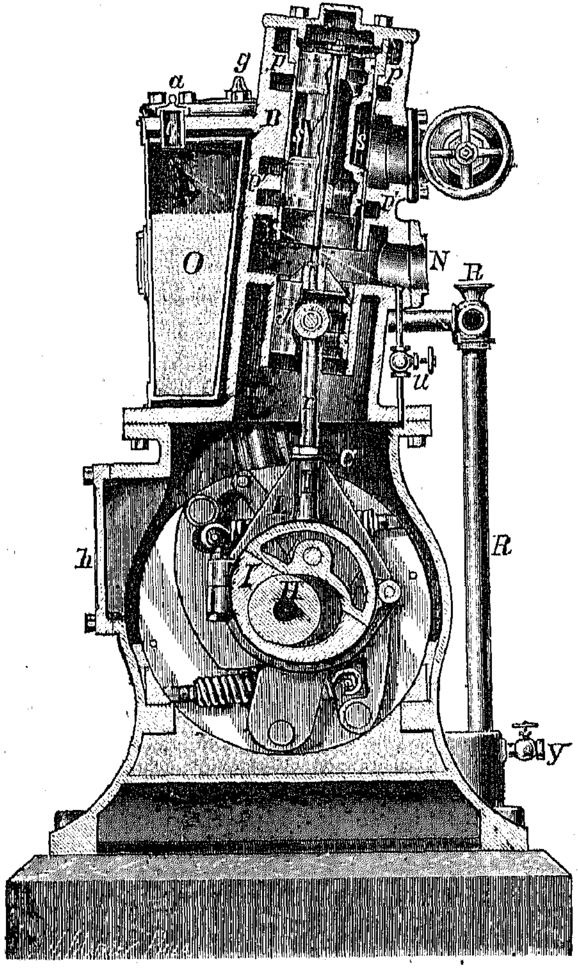

FIG. 30.—WESTINGHOUSE ENGINE, SECTION THROUGH VALVE-CHEST.

Much thought has been devoted to the design of engines which will lessen the necessity for skillful care and with features which will not permit of tampering. One builder claims his engine as "remarkable for what the engineer cannot do to it". Another guards against the mischief to which such machinery is liable from "the indiscriminate use of the monkey-wrench". Another casts upon his valves the warning words: "Let me alone." One builds an engine which requires no packing, and another, one which requires no keying-up, and not a few provide methods of continuous lubrication. Yet with all these precautions intelligence in the management of engines remains so important a factor, that the lack of it causes vastly more loss of power than the inherent defects of engines.

Economy in the use of steam.—There are some usages in the employment of steam for power which if intelligently applied would result in an enormous aggregate saving. While the marketing of engines of various designs has been actively furthered, the application of methods of economy, more or less available with all designs of engines, has not received due attention. These are chiefly superheating, steam-jacketing, the use of condensers, and compounding.

Steam-jacketing "increases the economy of an engine by supplying such an amount of heat to the interior walls as to prevent the condensation upon them of the entering steam, and although the amount of steam condensed in the jacket is very great, it is far less than that which it prevents. The best experiments show a saving of from 8 to 10 per cent. with well-loaded engines, and 15 per cent. or more with engines having a light load and excessive expansion". (H. A. Hill.)

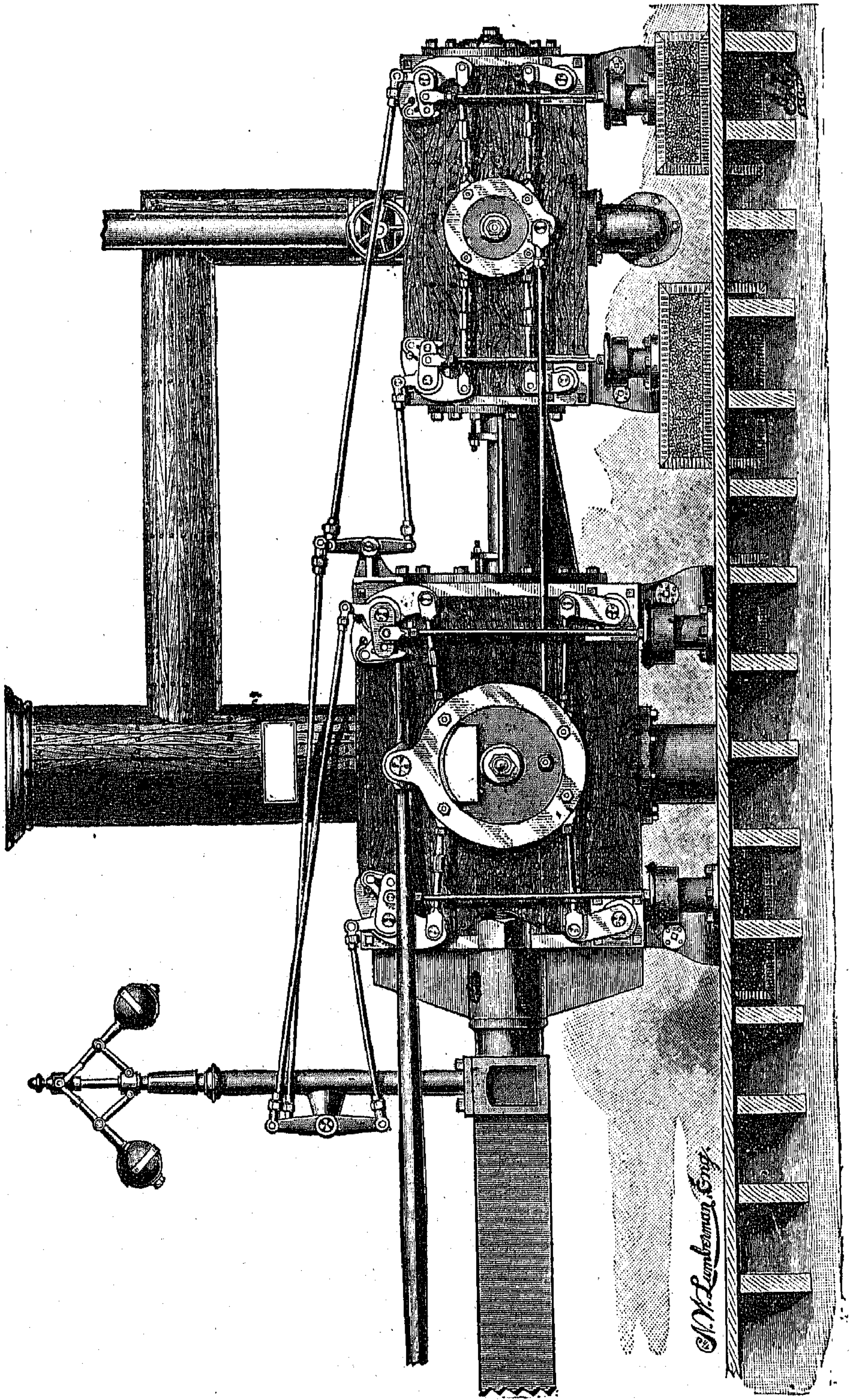

FIG. 31.—COMPOUND CORLISS ENGINE (MILWAUKEE, WISCONSIN).

Steam-jacketing is a less radical and less effective means of preventing cylinder condensation than superheating the steam. To the practical value of superheating and its proper application Mr. Charles T. Porter has given particular attention, and Mr. J. C. Hoadley has invented a form of boiler which affords a safe and reliable means of obtaining the moderate degree of superheat which is beneficial. Excessive and uncontrolled superheating will destroy packing and ruin an engine, but in the Hoadley device the degree of superheat is tempered and limited. It gives a temperature of 371 degrees to steam of 90 pounds pressure, which saturated has a temperature of 331 degrees.

Compounding, or the employment of more than one cylinder in which to utilize the expansion of steam, has a decided value. It lessens internal condensation by limiting the changes of temperature in any one cylinder. It also permits the use of such a ratio of expansion as will not render the clearance space so great relatively to the full admission as to cause a loss which cannot be easily remedied by compression. The transfer of steam from a smaller to a larger cylinder in the course of expansion involves a loss. Mr. Porter says: "There being no boiler to furnish an unlimited supply (note—as in ordinary high-pressure cylinders), but the supply being only the

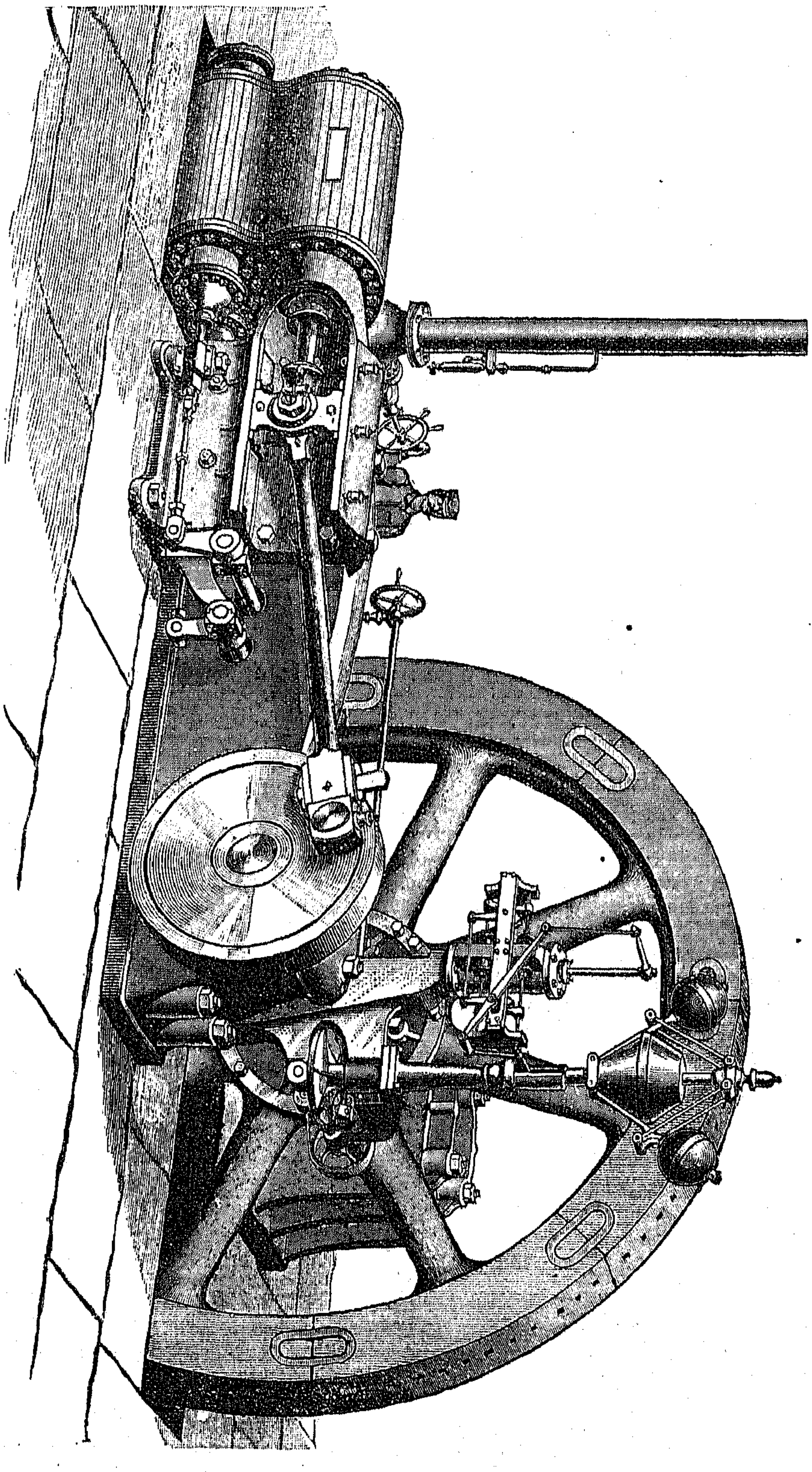

FIG. 32—HEAVY ROLLING-MILL ENGINE.

quantity discharged from the first cylinder, this loss from the condensation of the entering steam stands revealed. This fall of pressure is hardly ever less than eight pounds. I have known it to be as much as twenty-five pounds, representing a corresponding loss of heat". The remedy for this loss is found in the use of an intermediate receiver in which the water of condensation is drained off while the remaining steam is heated by a jacket.

In Fig. 31 is shown Mr. Edwin Reynolds's arrangement for compounding Corliss-engine cylinders, as built by E. P. Allis & Co. Here the cylinders are placed in "tandem" order, instead of being side by side with separate crank connections, as in the case of the Porter engines, to which the above-described steam-jacketed receiver is applied.

Respecting the Allis engines it is said:

> Repeated trials and tests have shown that with a compound condensing-engine properly proportioned to the load and steam-pressure a saving of 40 per cent. can be effected over a non-condensing-engine and 15 per cent. over a condensing-engine in the steam and fuel used to do a certain work. The steam is first admitted to the high-pressure cylinder, where it is expanded down to within 4 to 6 pounds of the atmosphere; it is then released into the receiver; from the receiver it passes to the low-pressure cylinder, where it is expanded a second time to about 9 pounds below the atmosphere, when it is released to pass to the condenser, thus forming a nearly continuous line of expansion from the boiler pressure down to 9 pounds below the atmosphere.

The gain obtainable by condensing may be reached without so great an outlay for machinery as is required for compounding. The air-pumps necessary are sometimes operated by connection with the cross-head or the main shaft of the engine. With the Porter-Allen engine the air-pump is driven by a belt through gearing, and in mid-summer, with the warmest injections, the power required to drive it does not exceed 1 per cent. of the power of the engine. Independent condensing apparatus with air-pumps operated by direct-acting steam-engines are considerably used, the Worthington, the Deane, the Knowles, and the Blake being familiar types. These employ jet-condensers, requiring under ordinary temperatures a weight of water 20 to 25 times the weight of steam condensed. The recent invention of a surface-condenser (F. M. Wheeler's), in which the difficulty of leakage of tubes is obviated, promises to be of advantage under some circumstances. The gain of power from condensing alone may be reckoned at from 20 to 50 per cent. Yet an engine running under a light load and with high boiler pressure may derive little or no benefit from a condenser, which would only serve to give it an earlier cut-off with a very serious increase of internal condensation.

The following account of trials of an automatic engine in a flouring-mill (Gibson & Co., Indianapolis, Indiana), made by John W. Hill, M. E., 1877, and published in *Van Nostrand's Magazine*, affords an interesting comparison of the performance of an engine condensing and non-condensing upon nearly the same work:

> Twelve run of 48-inch buhrs do the grinding; these are driven by belts, the line-shaft being coupled to end of engine-shaft, and revolving at same speed; the balance of machinery, cleaners, rolls, elevators, conveyers, bolts, purifiers, and packers, are all adapted to maximum capacity of grinding machinery.
>
> The engine is a Harris-Corliss single cylinder, 18 by 42 inches, speeded at 75 revolutions, with a 12,000-pound fly-wheel, 16 feet diameter.
>
> The boilers were opened and cleared of scale and sediment previous to trials.
>
> The coal fired is known as Highland (Clay county), a species of the celebrated Indiana block coal.
>
> During both runs the mill was worked at maximum capacity, quality and condition of wheat considered. It may not be out of place to remark that in this mill the Messrs. Gibson made what is known as patent process flour; thus of the 12 run of buhrs, 7 run operated on wheat, and 5 run on middlings, bran, and tailings. In making flour by this process it is customary to grind 7 to 8 bushels of wheat per hour per run of buhrs (48-inch); during the trials 7.5 to 8 bushels of wheat were ground per hour per run (wheat stones).
>
> The record of work in the mill was based on the barrels of flour packed; this being regarded as an approximate index of the amount of work done by balance of machinery; the amount of work done by storage elevator was greatest during non-condensing run.
>
> Hourly reports of condition of machinery in the mill were made by the chief miller, and entered in the writer's notes. The following table exhibits the amount of machinery driven and disposition during each run:

TRIAL CONDENSING.	TRIAL NON-CONDENSING.
Started 7.30 a. m., August 22.	Started 8.15 a. m., August 24.
7 run on wheat; 3 run on middlings; 2 run on red dog.	7 run on wheat; 3 run on middlings; 2 run on bran.
Cleaner.	Cleaner.
Rolls (2).	Rolls (2).
Bolts (all).	Bolts (all).
Purifiers (5).	Purifiers (5).
Elevators and conveyers (all).	Elevators and conveyers (all).
Packer (1).	Packer (1).
At 9.15 a. m., lightered 3 run on middlings.	Storage elevator.
At 10.15 a. m., changed 2 run from red dog.	At 8.30 a. m., changed 2 run from bran to red dog.
At 10.30 a. m., storage elevator on (to) bran.	At 9.55 a. m., changed 2 run from red dog to bran.
At 10.30 a. m., lightered 2 run on bran.	Storage elevator irregular.
At 1 p. m., storage elevator off.	Stopped 4.15 p. m.
Stopped 3.30 p. m.	

REMARKS.—Starting and stopping in above table merely denotes the time run was held to commence and end. The engine and machinery ran without interruption.

Performance of engine.

	Condensing.	Non-condensing.		Condensing.	Non-condensing.
Duration of run.....hours..	8	8	Extra friction horse-power due to load.....	4.885	5.387
Pressure in the pipe.....pounds..	58.50	76.37	Net effective horse-power.....	92.831	102.365
Temperature of injection.....	81.80	....	Per centum of indicated power available.....	88.014	88.684
Temperature of hot well.....	112.00	....	*Economy.*		
Temperature of steam at terminal pressure.....	203.19	....	Net steam per hour to engine.....	1961.03	2931.14
Barometer (assumed).....inches..	29.53	29.53	Net steam per hour per indicated horse-power.....	18.593	25.391
Vacuum in condenser.....do...	21.83	....	Net steam per hour per indicated horse-power by the diagrams.....	16.587	21.983
Revolutions.....	74.288	73.000	Per centum steam accounted for by indicator.....	89.211	86.578
Piston speed.....	520.016	515.200	*Cost of the power.*		
Horse-power due piston speed.....	3.954	3.917	Coal per indicated horse-power per hour.....	4.085	5.213
By the diagrams.			Coal per indicated horse-power per hour, evaporation 9 to 1.	2.076	2.832
Initial pressure (above atmosphere).....	57.015	74.042	Relative efficiency.....	100.00	73.30
Cut-off in parts of stroke (stroke 100).....	10.827	18.891	Economic gain by use of vacuum.....	36.41	....
Release in parts of stroke (stroke 100).....	100.000	99.000	*Cost of the flour.*		
Terminal pressure (absolute).....	12.329	19.581	Barrels ground and packed.....	89	93
Counter-pressure (absolute) at mid-stroke.....	4.594	15.933	Horse-power per barrel per hour.....	9.480	9.947
Exhaust closure in parts of stroke.....	3.478	8.816	Coal per barrel (actual).....	38.73	51.76
Mean effective pressure.....	26.928	29.471	Coal per barrel (evaporation 9 to 1).....	19.71	28.11
Friction pressure (assumed).....	1.962	1.962	Relative efficiency.....	100.00	74.826
The power.			Economic gain by use of vacuum.....	33.34	....
Indicated horse-power.....	105.473	115.437			
Friction horse-power.....	7.757	7.685			
Gross load horse-power.....	97.716	107.752			

The following tables of engine performance are taken from a publication of the Buckeye Engine company, Salem, Ohio. They show for three points of cut-off under specified initial pressures the resulting mean effective pressures for condensing and non-condensing engines, the terminal pressures, and the steam or water consumption with condensing and non-condensing automatic- and throttling-engines. The steam consumption is given in pounds per horse-power per hour. The rates marked "theoretical" are computed from indicator diagrams, those marked "actual", from experiment, in part, some of the figures being obtained by plotting curves through points established by the known data:

CUT-OFF 15/100.									CUT-OFF ¼.									CUT-OFF ½.									
Mean effective pressures.			Rates.					Mean effective pressures.			Rates.					Mean effective pressures.			Rates.					
			Actual.		Theoretical.						Actual.		Theoretical.						Actual.		Theoretical.			
Non-condensing.	Condensing.	Terminals.	Non-condensing.	Condensing.	Non-condensing.	Condensing.	Throttling.	Non-condensing.	Condensing.	Terminals.	Non-condensing.	Condensing.	Non-condensing.	Condensing.	Throttling.	Non-condensing.	Condensing.	Terminals.	Non-condensing.	Condensing.	Non-condensing.	Condensing.	Throttling.	Initial pressure.
9.05	19.05	9.07	54.0	30.0	31.3	16.8	64	17.84	27.84	14.40	39.0	22.0	27.2	18.5	46	30.50	40.50	27.78	41.0	29.5	28.5	23.4	39	40
11.32	21.32	9.87	47.0	28.5	27.7	16.4	56	20.89	30.89	15.81	36.0	21.5	25.3	18.2	44	34.75	44.75	30.33	39.0	28.8	27.6	23.1	38	45
13.59	23.59	10.72	42.0	27.0	25.3	16.1	51	23.45	33.45	17.13	33.5	21.0	24.0	17.9	42	39.00	49.00	32.88	37.0	28.3	26.9	22.8	37	50
15.86	25.86	11.55	38.0	26.0	23.4	15.8	47	26.50	36.50	18.45	31.2	20.5	22.9	17.6	40	43.25	53.25	35.43	35.5	27.9	26.3	22.5	36	55
18.12	28.12	12.38	34.5	25.0	22.1	15.6	43	29.56	39.56	19.77	29.0	20.0	22.0	17.4	39	47.50	57.50	37.98	34.0	27.5	25.8	22.2	35	60
20.39	30.39	13.20	32.0	24.0	21.1	15.4	40	32.61	42.61	21.09	27.0	19.5	21.3	17.2	38	51.75	61.75	40.52	32.5	27.1	25.3	22.0	34	65
22.66	32.66	14.03	30.0	23.0	20.3	15.2	38	35.67	45.67	22.41	26.4	19.0	20.8	17.0	37	56.00	66.00	43.07	31.0	26.7	24.9	21.8	33	70
24.92	34.92	14.86	28.0	22.2	19.5	15.0	36	38.72	48.72	23.73	25.3	18.5	20.4	16.8	36	60.25	70.25	45.61	30.0	26.3	24.5	21.6	32	75
27.19	37.19	15.69	26.0	21.3	18.8	14.8	35	41.78	51.78	25.05	24.0	18.0	20.0	16.6	35	64.50	74.50	48.16	29.0	25.8	24.2	21.5	31	80
29.46	39.46	16.51	24.5	20.4	18.4	14.6	34	44.83	54.83	26.37	23.0	17.7	19.6	16.5	34	68.75	78.75	50.70	28.0	25.4	23.9	21.4	30	85
31.72	41.72	17.34	23.0	19.5	18.0	14.5	33	47.89	57.89	27.69	22.0	17.4	19.3	16.4	33	73.00	83.00	53.25	27.0	24.9	23.7	21.3	30	90
33.99	43.99	18.17	22.0	18.7	17.6	14.4	32	50.94	60.94	29.01	21.2	17.2	19.0	16.3	32	77.25	87.25	55.79	26.0	24.5	23.5	21.2	29	95
36.26	46.26	19.00	21.0	18.0	17.3	14.3	32	50.04	64.00	30.33	20.4	17.0	18.7	16.2	31	81.50	91.50	58.34	25.0	24.0	23.3	21.1	29	100

The steam consumption for the throttling-engines is when running with the same boiler and mean pressures as the non-condensing engines of the same lines.

SIZES OF ENGINES USED IN VARIOUS MANUFACTURES.

The following figures show the average sizes of engines used in the specified industries in 1870, and are of value in indicating the sizes and powers used in these various industries, and the relative cost of power entering into the various products. The total power (water and steam) in respect to the value of product is shown by taking the total horse-power per hour by the number of hours for 300 days, divided by the value of the product in dollars. The average number of operatives per establishment is also stated:

Industry.	Average size engine in horse-power.	Horse-power per dollar's worth of product per hour.	Average number operatives per establishment.	Industry.	Average size engine in horse-power.	Horse-power per dollar's worth of product per hour.	Average number operatives per establishment.	Industry.	Average size engine in horse-power.	Horse-power per dollar's worth of product per hour.	Average number operatives per establishment.
Pig iron	115	2.75	71	Bleached and dye goods	42	0.29	17	Chairs	28	2.25	23
Cotton goods (see prints)	111	2.48	16	Printed paper	37	2.69	35	Bricks	28	1.00	13
Forged iron	104	2.22	121	Woolen goods	37	1.69	40	Ship-building	28	0.57	15
Nails	106	1.60	54	Railroad machinery	36	0.65	133	Sash, doors, and blinds	27	2.85	12
India rubber	90	1.29	108	Hats and caps	33	0.28	83	Hosiery	27	0.95	60
Sugar, refined cane	81	0.26	78	Drugs and chemicals	32	0.63	16	Soap and candles	25	0.52	7
Copper, milled and smelted	75	0.84	40	Sugar, raw cane	31	5.20	29	Agricultural implements	23	1.86	13
Carpets	67	0.51	56	Flour and grist	31	3.88	2	Cotton and wool machinery	23	1.33	20
Lead and zinc paint	61	1.42	26	Distilled liquors	31	1.13	7	Hardware	23	1.21	24
Cotton and woolen prints	55	0.54	212	Planed lumber	30	2.08	12	Stoves and castings	23	0.79	39
Milled quartz	47	2.06	10	Stone work	30	0.70	14	Cooperage	23	0.70	5
Worsted goods	47	1.09	127	Lead pipe	30	0.10	9	Engines and boilers	21	0.86	34
Sewing-machines	46	0.39	148	Sawed lumber	28	0.17	6	Coal-oil	21	0.47	11
Railroad cars	42	0.56	94								

In cases in which the material used is already a manufactured product the value of power in the whole manufacture is not indicated, but only that in the portion of the manufacture covered.

Cost of a horse-power.—The cost of a steam horse-power, like any other industrial value, varies considerably in different sections, as governed by the cost of transportation of fuel; at different times, as governed by the fluctuations of market values, and in respect to usage, as governed by the use of large or small, efficient or inefficient steam machinery. A fraction of the cost is always due to interest on investment, which may be assessed in various ways and with various allowances for the decadence of machinery.

In many classes of manufacture the employment of exhaust steam in sundry processes takes up the waste product of the boilers, so that economy of performance of the engines becomes of minor consequence. This is true of bleacheries, wool and straw-hat factories, dye-shops, tanneries, woolen mills, and other establishments using exhaust steam in the manufacturing processes. For example, at the Pontoosuc Woolen Mill, Pittsfield, Massachusetts, it is considered that, a large amount of steam being required in the dye-house in any event, they can get 100 horse-power for the mill by an additional use of coal to the amount of six-tenths of a pound per horse-power per hour. In northern factories, in which exhaust steam is used for heating, the exhaust of the engines does not usually furnish enough for the coldest weather, and live steam has to be used in part, so that the economy of the engine is lost in other requirements.

Of the cost of power in 1880 a few examples are given based on data as stated by various manufacturers interested.

In a factory in Worcester, Massachusetts, for a 60 horse-power engine the fuel used was mine pea, 270 tons, at $5 50=$1,485; the fireman and engineer was paid $500 salary; the cost of engines and boilers was $6,500, and the cost of investment and repairs was rated at 10 per cent. The cost of a horse-power per day was thus about 14½ cents.

In two factories at Hartford, Connecticut, the elements of cost per horse-power per day of ten hours were found to be—

	a.	*b.*
Interest on boilers and engines	$0 02	$0 02
Cost of attendance	04	02
Cost of fuel	10	07
Total	16	11

For a factory at Stamford the cost was, investment, 1 cent; attendance, 1½ cents; fuel, 9½ cents; total, 12 cents, and for another factory of similar power the cost was, investment, 1½ cents; attendance, 2½ cents; fuel, 7 cents; total, 11 cents. Such examples might be indefinitely multiplied, and with a market of fluctuating prices not a little depends upon the date at which the coal supply is obtained. In the west the cost of fuel is usually less, but as interest runs high, and the cost of machinery is often higher than in the east, the cost of steam-power does not appear very much reduced. An extreme case is that of an edge-tool factory close to a coal mine in a town in Pennsylvania. Here the fuel may be had for the taking, but the cost of investment is greater, as appears from the following estimate:

Interest on boilers and engines	$0 03
Cost of attendance	03
Repairs and contingencies	03
Cost of fuel (simply carting)	01½
Total	10½

The fuel was culm or duff—fine and dust coal which is sometimes burned like pine slabs to get its bulk out of the way. The steam machinery was inferior but costly. It is seen to have cost in two ways, in the first instance and for repairs.

Throttle-valve engines are commonly used in the west and south. For lumber-working, where the furnaces burn waste wood, and for cotton-seed-oil mills, in which the waste product serves as fuel, they are especially adapted. In every section the manufacturer, as is reasonable, tries to diminish the greatest element of cost, and alike consults his financial interests in getting a high-cost automatic engine in one case or a low-cost throttle-valve engine in the other.

Automatic engines first introduced as a superior product, covered by patent claims, of costly designs and with costly attachments, have heretofore been rated at much higher values for the power obtained than the plain slide-valve engines. The automatic engines of the drop cut-off type also ran at lower rotative speeds than the plain slide-valve engines, and with large ratios of expansion, required much larger cylinders for the same power. Upon the lapse of patent claims, and with the introduction of high speeds and positive-motion automatic engines of simpler designs, there is no question but that the sphere of this type of engine will be vastly enlarged, and that there will be a much greater saving in the aggregate cost of steam-power in the United States than we have already witnessed from this improvement of engines.

Portable engines.—In themselves portable and semi-portable engines, being usually of the plain slide- and throttle-valve type, present few features deserving of especial remark. The boilers used are of the locomotive and vertical tubular types in most cases. Sometimes horizontal return-flue or tubular boilers are used. For farm engines locomotive boilers are most common, the engine sometimes being placed on top and sometimes for easier access being bracketed to one side of the boiler, but whether the boiler used be horizontal or vertical the engine is almost invariably so placed that the main shaft shall be farthest removed from the fire-box of the boiler.

Boilers.—In the use of boilers, as of engines, we find similar degrees of economy attained by means of designs which exhibit great differences. In engines these differences are mainly confined to the details of governing mechanism, but in boilers they relate mainly to proportions, the efficiency of which varies greatly with the conditions of use, and as these conditions can not be known nor defined within a wide range, either by the builder or the user of the boiler, we find an innumerable variety of proportions. This variety is due in great measure to the methods of manufacture, which do not necessarily nor as an economic feature require uniformity of designs and patterns.

At the same time it can not be said that a greater uniformity is not desirable, and for the following reasons: In the first place, in the work of manufacture, uniformity of proportion makes more of what may be called "straight work", that is, work which is done over and over again until the boiler-maker is so habituated to it that he can do it just as it should be done every time. This is especially important in riveting, for with new forms of work continually taxing the ingenuity of the boiler-maker, there is more liability to discrepancy and to improper makeshifts, such as the use of the drift-pin. In the second place, a uniform design will be a good and safe design in order to commend itself to general use. While boiler explosions may not infrequently be due to sheer overtaxing of strength on account of too high pressure or of the violence of sudden fluctuations of pressure, they are in many cases caused by faults either of material or workmanship. It is also beyond question that the starting of cracks and flaws is often due to the treatment of the boiler by the steam user, to burning out from incrustations, to corrosion, and to unequal expansion. It is desirable that a boiler should not be so stayed or jointed that in getting up steam the parts should be strained by unequal expansion, or at least any more than is unavoidable. Uniformity would secure the best arrangement in this respect. In the third place, a greater degree of uniformity would furnish better facilities for inspection. The inspection of a boiler of peculiar design is a work of difficulty as well as of responsibility, and even after the boiler has been carefully examined, a conscientious inspector may not feel confident that it contains no lurking defect; but with a boiler of standard proportions, he can turn to the weakest points at once and feel reasonably confident that his work is thoroughly done.

Boilers of special design, such as the Lowe and the Babcock and Wilcox boilers, are likely to be made with greater uniformity of method as well as of product. The first Lowe boiler was put up in 1867 and has since had no repairs.

The farm portable boiler may be considered more liable to explosion than any other type. It is racked by motion. It is handled by men who are not engineers. Unlike the boilers of large factories, it does not have skilled care, nor is it so often guaranteed by local and insurance inspectors. Unlike marine and river-boat boilers, it is not subject to government inspection. And although these boilers are employed in large and increasing numbers, of portable boilers of all kinds, including boilers for the engines of threshers, hoisters, pile-drivers, and cotton-gins, there were reported only 13 explosions in 1880, out of a total of 170 explosions of all kinds of boilers. It is probable that in future years the rough usage of this class of boilers will find its outcome in a larger percentage of casualties, but some parties who build them largely have never had a boiler of their manufacture burst. Tanner & Co., of Richmond, Virginia, make this claim, though of course boilers however well made can not resist every exaction of time, corrosion, and ill usage. But the point which I wish to make is that these portables are built in lots and of uniform and simple designs without much flanging, thus securing more uniformly reliable workmanship.

In respect to unequal expansion, stays intended to strengthen a boiler have been so placed that they have operated under unequal expansion with a thrust or leverage tending to produce strains and cracks. Here again a uniform and approved practice would be a safeguard.

In the east, the return tubular boiler is the prevailing type for manufacturing purposes, but locomotive fire-box boilers are often used. In the west, return tubular boilers are used, but the return flue-boiler is the more common type, both of these types of boilers being fired externally. In some cases, notably in iron works, flue and plain cylinder boilers of great length (sometimes 50 or 60 feet long) are used. These are hung in supports, and the expansion of the top and bottom of the boilers being unequal, the central supports have in some cases been broken down, causing disastrous explosions, which rend the boilers asunder in the middle. Expansion is always more troublesome for great lengths. Thus, in laying steam-pipe, it is difficult to keep a long line of pipe steam-tight without some form of expansion joint.

In the west we find in practice no dividing line between flue and tubular boilers, the usage passing from cylindrical boilers to large flue boilers, and thence to boilers with 10-inch, 8-inch, 6-inch, 4-inch, and 3-inch flues or tubes. The flue boilers do not give as large a heating-surface as the tubular boilers, but by reason of better circulation their heating-surface may be more valuable for the same area, and they are more suitable for ordinary usage, impure water, and a low grade of fuel.

Heating-surface differs greatly in quality in the different parts of a boiler, and it is possible, under some forms of construction, that surfaces so estimated may actually become cooling-surfaces, or, at least, heating-surfaces whose good effect is almost nullified. In the journal "Locomotive" an ingenious, but simple, experiment is mentioned, showing the relative values of the heating-surfaces of tubes at different heights in the boiler. A small white pine stick is set up against a row of tube-holes, and becomes charred in bands opposite each tube; but when the stick is charred and burned through opposite the top tube it is scarcely scorched opposite the bottom tube, while the intermediate tubes illustrate, by charring the stick, a regular gradation of heat from top to bottom. The inference is that it is better to leave out the bottom return tubes, so as to give more water-volume for the direct heat of the furnace and combustion-chamber to act upon. Neither is it wise to impair the circulation by overcrowding the boiler with tubes.

In respect to the rating of boilers by so-called nominal powers, estimated in square feet of heating-surface, it may be said that such methods give a commercial name to an article, and that is all. The efficiency of a boiler once set may be altered by a change of fuel or method of stoking, by a forced draft, or even by a high wind, but we do not find boilers proportioned by any exact methods to meet particular requirements, because such requirements practically vary enough to upset the results of nice calculations. Boiler management may be considered to be yet in its infancy, so far as exact quantities are concerned, but a system of stoking which will secure some degree of uniformity, and a positive, quantitative, and mechanical regulation of the draft, are the conditions of the best results possible. If the steaming capacity of a boiler is known in pounds water per hour evaporated from 212°, under the ordinary pressure of 70 pounds, the steaming capacity sufficient to develop a horse-power varies from 15 to 40 or more pounds steam, according to the use and character of the engine. By forced draft, boilers may be made to make more steam, but not economically, unless the grate-surface be reduced. Air admitted above the grate helps to complete the combustion of the gases and of the particles of carbon in suspension (smoke), but it also dilutes the hot gases, and thus heat which would have gone into the steam may be carried out at the chimney.

Boilers for stationary and manufacturing purposes may be divided into two principal classes, viz, those with external and those with internal furnaces. The former, comprising nearly all return tubular, flue, and cylindrical boilers, are most generally used. They are obviously cheaper to build and involve less iron work than a boiler which contains the furnace within its shell. They are not always the most economical of fuel, but in employing them users are supposed to consult the considerations of first cost and expense of fuel, as one would do in choosing between an automatic cut-off and a slide-valve engine for a specified service. Some heat is expended in warming the exterior walls of masonry in external furnaces, but this loss is slight.

Boilers with internal furnaces are very largely used in New England and the east. These are for the most part of two types, locomotive-tubular and drop-return boilers. In these the furnace is within the water-space of the boiler, and the products of combustion are conducted back by tubes or flues directly through the boiler, and in the drop-return boilers find their way to the chimney through flues at a lower level leading toward the front end of the boiler and thence to the chimney. A form of drop-return boiler, highly approved for economy of fuel and largely used in New England, is the Lowe boiler. This has a combustion-chamber above the furnace, which communicates with it by two circular side passages. Thence the products of combustion pass through tubes to the back of the boiler and thence drop and pass under the boiler up by side flues and back over the top of the boiler to the chimney.

In some large factories the practice prevails of having ample boiler power or capacity and keeping each of the boilers "resting" some of the time under the idea that it conduces to their durability. However this may be, the attempt to get a large amount of steam by using a small boiler is certainly conducive neither to the durability of the boiler nor to economy of fuel. The economical rate of combustion is limited to about three-tenths pound of coal per hour per square foot of heating-surface. A first-rate boiler, evaporating 3 pounds of water per square foot of heating-surface per hour, will evaporate about 9½ pounds water per pound coal. If it evaporate only 2 pounds of water per square foot of heating-surface per hour, it will evaporate from 9½ to 10 pounds water per pound coal, and if it evaporate only 1 pound of water per square foot of heating-surface per hour it may evaporate as much as 10½ pounds water per pound coal. These figures are for dry steam and ordinary conditions, viz, a feed temperature of 60°, steam pressure raised to 70 pounds per square inch, and coal used a good quality of anthracite containing about 90 per cent. combustible. If the boiler "prime", that is, cause water to pass off with the steam, a great weight of water per pound coal used may be made to pass through it, but it will be a weight of water and not of steam, and will be wasteful and injurious in its effect upon the steam machinery in which it is used. Thirteen pounds water per pound combustible is usually stated as the best attainable result with the most favorable conditions likely to be found outside of the laboratory. Very often not more than half this result is realized. In the direction of economy and durability there is no more notable movement than that of the introduction of feed water-heaters and purifiers, the use of which, in a great variety of designs, is largely on the increase.

Water-tube boilers.—Various forms of sectional and water-tube boilers have been introduced, designed to secure greater safety without sacrifice of economy. The most prominent among these is the Babcock and Wilcox boiler. In this there are a series of inclined water-tubes, sloping from the furnace front downward and backward, and connected with a mud-drum at the back and a horizontal steam- and water-drum at both ends, this drum being located above the tubes. The tubes are set "staggered" in end connections (in which they are fixed by an expander), while opposite each tube is an opening, closed by a hand-hole, plate-jointed, and rendered steam-tight by means of accurate milled surfaces. The boiler is largely used in the east, and is highly efficient. There is a continuous circulation of water descending from the upper drum through the back connection and passing up toward the furnace through the inclined tubes. In durability, ease of cleaning, freedom from priming, and rapid steaming, its good qualities have been demonstrated by some fifteen years of use. The space for combustion is ample, and the boiler is so hung from wrought-iron girders, independent of the brick-work, that there can be no serious strains due to unequal expansion.

Safety of boilers—Inspections.—The following statistics are furnished through the courtesy of the Hartford Steam Boiler Inspection and Insurance company. This company was chartered in 1866 and its object is not insurance primarily, but safety through inspection, the insurance being a guarantee of the work of inspection. For the entire United States the following explosions were reported during the years 1879 and 1880:

Kind of works and service.	1879.	1880.
Sawing, planing, and wood-working mills	41	47
Railroad locomotives and fire-engines	16	18
Steamboats, tugs, dredges, and dry-docks	13	15
Paper-, flouring-, pulp-, and grist-mills and elevators	10	19
Portables, hoisters, threshers, pile-drivers, and cotton-gins	9	13
Iron works, rolling-mills, furnaces, founderies, machine- and boiler-shops	10	13
Tanneries, belt and leather works, shoe and hat factories	......	2
Cotton, woolen, knitting, and other textile works	8	2
Distilleries, breweries, malt- and sugar-houses, soap and chemical works	8	10
Mines, oil refineries, and oil wells	4	8
Bleaching, digesting, dyeing, print-works, slaughtering, etc	4	3
Steam heating and drying. dwellings, schools, stores, and public buildings	......	2
Miscellaneous and mills not designated	9	18
Total	132	170

Between October 1, 1867, and January 1, 1880, records of 1,299 boiler explosions in the United States were obtained at the office of the inspection company, these including nearly all, and all of the more serious explosions in the country. They are classified as follows in respect to the character of service of boilers and the injury and destruction of life resulting from the explosions:

	Number boilers exploded.	Number persons killed.	Number persons injured.
Saw, planing, and wood-working mills	281	497	576
Steamboats, tugs, yachts, and steam-barges	186	956	816
Railroad locomotives	185	249	238
Iron works, furnaces, foundries, and machine-shops	92	147	[illegible]
Paper-, flouring-, and grist-mills, bleacheries, and print-works	92	96	122
Portable, hoisting, threshing, and pile-driving	66	143	137
Cotton-, woolen-, flax-, and other fabric-mills	55	72	131
Mines, quarries, oil-mills, and refineries	44	73	76
Heating and domestic boilers	29	10	33
Chemical, rendering, and slaughtering works	27	43	32
Distilleries, breweries, and sugar refineries	25	18	34
Miscellaneous (52 kinds of service)	217	201	93
Total	1,299	2,505	2,612

Up to the close of the year 1879 the company made (in a series of years) 92,850 thorough annual inspections, in which 31,183 dangerous defects were discovered, beside a much greater number of minor defects. But confining ourselves to such defects as were esteemed to involve peril to life and property, they were by number and kind as follows:

Fractures	5,079	Safety-valve overloaded	1,393
Cases of deposit of sediment	3,230	Cases of internal corrosion	1,124
Blistered plates	3,032	Water-gauges out of order	1,148
Burned plates	2,845	Furnaces out of shape	1,008
Pressure-gauges out of order	2,824	Blow-out apparatus out of order	802
Cases of incrustation and scale	2,756	Cases of internal grooving	444
Cases of external corrosion	2,665	Cases of deficiency of water	426
Broken braces and stays	2,171	Boilers without gauges	236

One thousand four hundred and sixty-three boilers were condemned altogether. The whole number of defects discovered, including those esteemed to involve no present danger, was 142,032.

Whether from a humane or from a merely commercial standpoint, the influence of an agency which has obviated so many perils must be highly esteemed.

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