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The Manufacture of Hydraulically Forged and Rolled Solid Steel Railway Wheels.

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Railway transportation, with its problems—road bed as well as rolling stock—has in later years claimed more than its share of capital and inventive thought, and as was naturally to be expected, in no other field of engineering have the undertakings been on as large a scale or of more practical and scientific interest to our profession.

It has been the speaker's fortune to have been associated with the development of the steel car, and, as his experience in this field has been somewhat extensive, the necessary results of the introduction of that car, and its technical requirements as to details, became early very apparent.

Immediately upon the introduction of the 100,000-pound car, the repair sheets of the different railways showed abnormal accounts, thus on the face of it tending greatly to eliminate the possibility of the adoption of this new innovation in transportation. A little investigation, however, proved that an unexpectedly large amount of the expense was caused by breakage of the wheels, and having no direct bearing upon the car structure proper.

That such should be the result was, after all, quite natural, when one considers that though the car capacities were but recently increased from 60,000 pounds up to 80,000 pounds, and finally up to 110,000 pounds, the substructure proper, which is represented by the wheels, was practically left untouched, barring the occasional adding of 50 to 100 pounds in weight, a heavy iron wheel of 33 inches diameter weighing to-day about 750 pounds.

It is also pertinent to recall, in this connection, that both the axle and the rail have been increased in large ratios to

sustain the increased duties. The swaying of the heavy steel car, in connection with its increased static load, proved, in many instances, ruinous to the flanges when passing switches or curves; and Mr. Schoen, the inventor and promoter of the steel car, suggested several years ago the possibility of applying a solid steel wheel, because of the fact that no additional weight or thickness could be given to the wheels at the spot where they most needed it, namely: at the root of the flange. In fact, the full economy of the large capacity steel car has never been realized, nor will it be until supported by a wheel, the flange of which will permit increased mileage with a practical elimination of wrecks. With this in view, all data and processes bearing upon the subject were investigated, and, about two years ago, the writer undertook to design for Mr. Schoen a plant to accomplish the purpose with a final result, the success of which is witnessed by the samples herewith shown to you, as well as by the wheels now being tried on the different railways; and again, as indicated by the photographs of the machinery and product which are attached to this paper.

The development of a perfect wheel is a matter of evolution. The first step in this series, after making the plain cast-iron wheel, was to make it with chilled tread. The next, in order to secure safety, was to make a steel tire and fit it to a wheel center. This style of wheel is now used almost exclusively throughout Europe, and to a considerable extent in the passenger service of this country; but, as there is a great deal of work expended in producing such a wheel, it naturally becomes very expensive. It appears that the ideal product should be made of steel of proper quality, all in one piece and forged and rolled to a perfect finish.

In order to make a successful steel wheel the balance sheet must again, first of all, be taken care of, and with this in view the price of such a wheel must be limited to a figure which shall bear a certain relation to the one of cast iron. In order to throw some light on the subject, the writer secured, a few years ago, some information from one of our leading railways, which will enable us to form an approximate opinion. It was found from two years' run, covering

5,320 cast-iron wheels (33 inches diameter and all legitimately worn out), in passenger service, that the average life per wheel was 56,000 miles. One hundred steel-tired wheels of the same diameter, and used in the same class of service, and similarly worn out, had an average mileage each of 265,000, or a ratio of 4.71 to 1 in favor of the steel wheel. Two hundred and sixty-five thousand miles is a very conservative estimate for steel wheels, because individual records of wheels show mileage as high as 380,000; showing what, under proper conditions, can be looked upon as a possibility.

Referring to the application of steel wheels for freight service, the railroad in question kept no records of the mileage for any wheel used in this branch of service; but with cast-iron wheels, the date of the wheel as cast upon it will give the desired information. During the same years 62,461 wheels, all legitimately worn out, were withdrawn from the service, representing an average age per wheel of eight years and three months. The average mileage per year of a freight car, as taken on the same railroad and during the same years, appeared to be 9,243. Multiply the average life of a wheel by the average yearly mileage of the car, and the result will give a fair approximate value of the average mileage per wheel for its entire life.

Pursuing this process, the average mileage of a cast-iron chilled wheel in freight service was found to be 76,260. There were no steel wheels used for freight purposes; but if we assume that the proportion between the life of a steel-tired wheel and a cast-iron chilled wheel remains the same, whether in passenger or freight service, the average life of a steel-tired wheel, under a freight car, would be 360,000 miles, or representing a life of over thirty-five years.

The above mileages are based upon the practice of the average wooden 60,000-pound car, and must be greatly modified when applied to the modern 55-ton structure. It has been stated by the representatives of one of the greatest freight-carrying railroads of the country, that the average mileage of a cast-iron wheel, when carrying the large capacity steel car, is about 35,000; and if we use this figure

as a basis, the life of a steel wheel should be in the neighborhood of 150,000 miles when based upon the data previously given. Using these two figures as a foundation for a financial comparison, the following data explains itself :

Assume as average service of cast-iron wheels (miles)	35,000
“ “ “ “ “ steel “ “	150,000
“ “ cost per wheel of cast-iron “	\$8 75
On this basis the cost of each 150,000 miles of service, with cast-iron wheels, would be	\$37 45
Less scrap value of about 4.25 cast wheels at 70 cents per hundredweight	17 98
Net cost for 150,000 miles with cast-iron wheels.	\$19 47

Adding to this last figure the value of a scrap steel wheel, which is about \$5, we find the allowable price for a wheel of this type to be \$24.47, not allowing for any other saving due to immunity from wrecks, as caused by defective cast-iron wheels, etc.

In the above it has also been assumed that the boring and mounting of the different cast-iron wheels is about equivalent to the “truing up” of the steel wheel.

Another point, which may be worth mentioning in this connection, is the fact that as the cast-iron wheel weighs at least 700 pounds, while the steel wheel weighs about 80 pounds less, there is a saving in dead weight per car of at least about 640 pounds.

The process as used in the manufacture of our new wheel is about as follows :

A round ingot, approximating in outlines the shape of a wheel, but of a quite smaller diameter and greater web thickness, is placed in a movable bottom die-holder of a 5,000-ton forging press; this machine being illustrated by Plate I, where the blank is first reduced in thickness. During this same stroke the hub is forged and finished and the hole punched—all in one operation. The original blank or ingot is about 4 inches less in diameter than the finished wheel, and its central body has a thickness of from 2 inches to $2\frac{1}{4}$ inches, which is reduced by rolling to a final web thickness of wheel of from $\frac{7}{8}$ inch to an inch.

Plates II and IIa represent the general drawing of the

mill, showing also part of the engine, while Plates III, IV, V, VI and VII are different views taken from the works recently erected in Pittsburg by Mr. Charles T. Schoen for the manufacture of the new wheel, and which represent the interior of the mill building with machinery and product, and also part of the power-house.

The forging press consists of a large bottom cylinder located below the floor, working through vertical, hollow-forged nickel steel 15-inch bolts on a movable cross-head, to which the top die is attached. The bottom die holder is stationary from a vertical point of view; but is operated horizontally by a hydraulic cylinder, so as to facilitate the introduction of the blank and removal of the finished product. Above the forging cross-head with its top die, is located another large hydraulic cylinder in which works a piston, the lower end of which engages into the cross-head and is guided by the same. This piston performs two functions, viz., first, of punching the hole, after which the piston continues downward, coming to a stop inside the forging cross-head, adding its pressure to that already existing upon the top die, and hence finishing the hub under the combined pressure of the two rams, which amounts to about 5,000 tons. The punches are not stripped; but they are split automatically, leaving the lower half remaining in the wheel blank, and this is afterwards removed before going to the rolling-mill. Most of the mechanism is automatic, and hydraulic cranes are attached so as to minimize labor.

The two conical rolls of the rolling-mill are driven by a 1,000-horse-power engine, the general arrangement of which is all shown on the photographs. Electric alarms call the attention of the operator when the thickness of the web and the rim have reached their limit. The work of the actual rolling process consumes from one and one-half to two minutes.

The third and last step is the coning of the wheel, which is done in a separate 1,000-ton press that is provided with the proper dies and handling mechanism. In this machine the rim is pushed downwards so as to give the proper relation between the edge of the hub and the edge of the flange, and

it should be added here that this peculiar shape of the wheel furnishes a small degree of elasticity, which is beneficial under load.

The entire three processes are performed in one heat, and the transportation machinery, from furnace to press, from press to rolling-mill, and again from the rolling-mill to the last press, are all worked out so as to be as near as possible automatic, and will reduce the entire complement of workmen, including heaters and boys, down to about ten or twelve, this number also covering the men who are handling and distributing the cold blanks previous to charging.

Patents for all this machinery have been applied for throughout the leading countries of the world, and most of them have already been granted. The industry represents mechanical problems absolutely unique, and of great interest to the engineering fraternity.

It is readily seen that in designing the different tools which make up this process, as well as in selecting the process itself, the main mechanical point in view has been to put as much work on the material as possible, and, when referring to the rim, it is perfectly natural that, in order to secure a homogeneous metal in this part of the wheel, it is of interest not to have too much material congregated at that particular place. From financial reasons one would arrive at the same result; because when considering the long life of a steel wheel, the increased first cost, with its compound interest, due to the carrying of this additional thickness for a number of years, will tend to counteract whatever benefits might be derived by having a little longer life.

It must also be remembered, that as the wheel is a solid finite and self-contained structure, with the rim rigidly connected to the web, it is possible to run with a thickness of rim that would be absolutely prohibitory with a tire, because in this latter case such a thickness, not being backed up by anything but its own inherent strength, would be stretched by the rolling action and become loose on its center.

While on the subject of finance, we might also refer to the cost of the steel-tired wheel. It must be understood that

the great underlying purpose for the introduction of the solid steel wheel is not directly one of competition with the center and tire construction ; but is rather to be considered as a forward step in the freight trade. And with this in view, it is pertinent to say that should it even be impossible to claim the same amount of molecular work done on the metal, and also the same high excellence generally for the solid steel wheel as that which is claimed for the steel-tire construction, the difference, however, would be so small as to be of little account when considered in the light of the difference in the market prices of the two products.

In order to throw all possible light upon the effect on the metal as caused by this process of manufacture, and referring especially to the result of the kneading action in the rolling-mill, some experiments were made by Messrs. Williams, Brown & Earle, here in Philadelphia. A section of a wheel was given to the above firm to be highly polished, etched, magnified under a microscope and subsequently photographed. This magnification was about 50 to 1, and when making allowance for the magnification in the lantern the picture as thrown upon the screen will have been magnified in a ratio of about 1,500 to 1.

In order to form a better comparative opinion, pieces of the original and untreated blank were also investigated by the same concern and in a similar manner. The first two pictures, Plates VIII and IX, as thrown upon the screen, represent the original metal, the lighter being of a little denser structure than the darker one, though both show an entire absence of any uniformity or regularity in their molecular make-up. The next two, Plates X and XI, however, are taken from part of the rim of the finished wheel, and show a decided beneficial effect of the processes through which the wheel has passed. The last picture, Plate XII, is simply a photograph of the section which was treated as above, and as it was intended for mere experimental purposes it had never been coned, the web being left straight as it came from the mill. The tread shows cut marks where it was parted so as to furnish a smaller piece to facilitate handling in the microscopical and photographic apparatuses.

PLATE VIII.

PLATE IX.

PLATE X.

PLATE XI.

PLATE XII.

If it is of great importance to have a maximum amount of work done on the metal, it is even still more necessary to have a metal of the proper chemical composition. With this in view, inquiries were made in the engineering department of a large trunk line to ascertain which composition of tire produced the best result, realizing what was good for a tire would naturally be equally good for a solid steel wheel.

The mileage of several compositions were given, and the comparison between them resulted in a metal which is our present standard, and which runs about as follows:

Carbon	about '7 per cent.
Manganese	'65 to '70 " "
Silicon	'3 " "
Sulphur and phosphorus, both below	'05 " "

The physical test showed an elongation of about 13 per cent. in 2 inches, with a contraction of about 35 to 40 per cent., and an ultimate of about 125,000 pounds per square inch.

It may be of interest to know the practices in this line of foreign railways, and with that in view I have copied the following specifications from a trade catalogue published by one of the leading makers of steel tires:

ENGLISH PRACTICE.

CHEMICAL ANALYSIS.

Carbon	'65 to '75 per cent.
Silicon	'20 to '25 " "
Phosphorus	under '05 " "
Manganese	'50 to '55 " "
Sulphur	under '045 " "

PHYSICAL TEST OF STEEL OF ABOVE ANALYSIS.

Tensile strength	115,000 to 125,000 pounds.
Elastic limit	55,000 to 60,000 " "
Elongation	10 to 15 per cent.

RUSSIAN PRACTICE.

CHEMICAL ANALYSIS OF STEEL.

Carbon	'50 to '60 per cent.
Phosphorus	under '05 " "
Silicon	under '25 " "
Manganese	'50 to '70 " "
Sulphur	under '05 " "

PHYSICAL TEST OF STEEL OF ABOVE ANALYSIS.

Tensile strength	85,000 to 100,000 pounds.
Elastic limit	45,000 to 50,000 "
Elongation in 2 inches	17 to 22 per cent.

JAPANESE PRACTICE.

CHEMICAL ANALYSIS OF STEEL.

Carbon	'55 to '65 per cent.
Silicon	under '20 " "
Phosphorus	under '05 " "
Manganese	'55 to '65 " "
Sulphur	under '045 " "

PHYSICAL TEST FROM STEEL OF ABOVE ANALYSIS.

Tensile strength	100,000 to 107,500 pounds.
Elastic limit	50,000 to 55,000 "
Contraction of area	20 to 29 per cent.
Elongation in 2-inch section	15 to 18 " "

FINLAND STATE RAILWAYS.

CHEMICAL ANALYSIS.

Carbon	'50 to '60 per cent.
Silicon	under '20 " "
Phosphorus	under '045 " "
Manganese	'50 to '60 " "
Sulphur	under '045 " "

PHYSICAL TEST FROM STEEL OF ABOVE ANALYSIS.

Tensile strength	92,000 to 100,000 pounds.
Elastic limit	46,000 to 55,000 "
Elongation in 8 inches	15 to 18½ per cent.

Since the commencement of the agitation in favor of a solid forged, rolled steel wheel, the makers of the old cast-iron chilled product are brought face to face with a new innovation, and many arguments in favor of their own wheel and objections to this new one were advanced. It has been said that the introduction of the new steel wheel would force railroads to purchase and operate lathes to an extent that would be prohibitory in order to keep the steel wheel up to its standard. If the life of a steel wheel, with all its turnings, were no greater than the life of a cast-iron wheel, such arguments would be true. But if the time between the turnings of the steel wheel represents a mileage equal to that of a cast-iron wheel—and which it should do—

there would be no more dismantlings than what at present exists in ordinary car practice.

The above statement is based upon cast-wheel mileages of 70,000; but, as previously mentioned, the experience of at least one of the great trunk lines has cut this figure down to from 30,000 to 40,000 miles when operated in connection with the 100,000-pound cars, and in such a light the dismantlings for the steel wheel are of still less importance.

It has also been argued that good cast iron represents a metal for wheel purposes which is superior to steel, as it flakes less and, barring the question of strength, is a better all round metal when provided with a chilled rim.

I am not here to belittle the merits of the cast-iron wheel; on the contrary, its introduction, with its many magnificent qualities, enabled industrial progress to an untold degree; but, unfortunately, as competition became greater less care was used in the selection of the iron, and instead of having a metal of charcoal material, with an ultimate resistance of from 30,000 to 33,000 pounds, the wheels of to-day are made of iron ranging between 20,000 and 22,000, and at times hardly that. Such is the fact independent of any theory, and it is with this low-grade wheel that we have to deal.

I do not deny that it may properly be asked: If a better cast iron were substituted, what would be the result? The most pertinent reply that can be given to this query is, that all would have been well and the steel wheel would not have become a necessity, if the world had not seen the introduction of the steel car.

It goes without saying that when frogs and switches actually prohibit the increase of dimensions only one other alternative exists, namely: increase of tensile strength; and this last step in the evolution of the car wheel became, hence, a necessity and, as I also trust, has now become an accomplished fact.

Barring the records of individual railways, no concerted action has been taken in this country to keep and maintain a national record of the life and accidents to railway wheels. In Germany, however, an association was formed about ten

to fifteen years ago which included the German State Railways, the Austrian-Hungarian State Railways and a few other independent roads. This association has taken a great deal of care in the matter of wheels, comparing damages to different constructions as well as to different metals. There are, of course, no rolled steel wheels in their territory; but a number of cars, with a few locomotives and tenders, have been equipped with solid cast-steel wheels, and it is interesting to note the results, though their number is somewhat too small to form very conclusive opinions as to details.

During the years 1887 to 1896, the total number of tired wheels varied from 1,700,000 to 2,300,000, while the total number of solid steel wheels commenced at 340,000 and increased to 375,000, most of which latter were, as already mentioned, placed under cars generally carrying freight.

It was found that the percentage of loss—this includes cracks and fractures—in the steel-tired wheels was about .18 per cent. in 1892, increasing up to .22 per cent. in 1894 and 1895, while with the solid steel wheels during the same period, the total loss was about one-half of 1 per cent. In steel-tired wheels the relation of cracks to fractures was about 7 to 10, while with solid wheels the fractures were so rare that as a matter of comparison they can be ignored.

The above indicates clearly, from a point of general result, the superiority of the forged and rolled rim as compared to that of the coarse, crystalline cast metal.

The German report furnished some data on the question of temperature which may be of interest to our profession in this country.

The total damage done to steel-tired wheels during any one summer month, as compared to the month of January, is one to ten. This heavy mid-winter destruction lasts only for a short time, reaching its maximum during the month of January, while during the five summer months the minimum will remain practically constant. With solid steel wheels this relation was as one to four, showing the beneficial result of a solid web.

The German data indicated that the maximum damage

~ STEEL TIRED WHEELS. ~

PLATE XIII.

~ SOLID CAST STEEL WHEELS. ~

PLATE XIV.

~ Theoretical Diagram of a forged and rolled Steel Wheel. ~

PLATE XV.

Diagram showing Comparison between Cast Steel, Steel Tired and Rolled Steel Wheels. ~

PLATE XVI.

was done with heavy tires, which I naturally suppose means that if a tire is imperfect the defects will develop shortly upon the wheel being placed upon the road. Illustrating this point, the following figures give a very interesting summary (the total damage done being considered as 100 per cent., including fractures and cracks, and the wheels representing the sum of both types, cast steel as well as tired).

Six per cent. of all the damage was done on mileages above 190,000; 30 per cent. was done on mileages between 100,000 and 190,000; 23 per cent. was done on mileages between 70,000 and 100,000, and 25 per cent. was done on mileages between 35,000 and 70,000.

The lessons derived from the above data, and as taught us by our German fellow engineers, would certainly seem to warrant us in drawing the conclusion that the solid forged and rolled steel wheel would have a rim which should possess very many of the meritorious qualifications of the steel tire, coupled with the advantages and the inherent strength afforded and shown by the web of the solid cast-steel structure.

The diagrams shown on Plates XIII, XIV, XV and XVI illustrate graphically what already has been said regarding temperature and wheel damages, cracks and fractures being shown separately.

The two first cards give directly the German results for steel-tired and cast-steel wheels, while the third card, representing the rolled steel wheel, is a theoretical construction based upon the German data for fractures with the cast steel wheel, and cracks with the steel-tired type. Such a combination ought to be one which this new construction should closely approximate.

The fourth card shows the total damages for all three kinds of wheels, and it is seen here that the solid wheel with the rolled rim shows the best efficiency.

In the history of the world industrial progress has been emphasized by certain landmarks, and I believe that among these epoch-making events those that refer to transportation on water or land are the greatest of all.

PLATE III.

PLATE IV.

PLATE V.

PLATE VI.

PLATE VII.

A few years ago, at a festive gathering of a number of remarkably able men, the question arose as to the relative importance, financially, industrially as well as ethically, of the leading inventions and discoveries recorded in the annals of history. The mariner's compass, the printing press, the steam engine, the laws for movement of matter, the discovery of the blood circulation, the anæsthetics, etc., were all reported in due order. The host, who was president of one of the greatest trunk lines of the world, remained silent. Finally, when one of his guests addressed him with a request to mention *his* choice amongst the great meritorious facts, his answer was prompt—"the flange of a car wheel."

DISCUSSION.

MR. ARTHUR FALKENAU:—I should like to know from Mr. Loss of what kind of material the punches are made.

MR. LOSS:—After a number of experiments we decided in favor of fairly hard cast iron as possessing the best average combination of durability and cheapness.

MR. W. VOLLMER:—I should like to ask Mr. Loss about the number of wheels at present in service. Also about their length of service and the mileage covered as well as their general efficiency.

MR. LOSS:—Last June about thirty experimental wheels were placed under locomotive tenders on different railways and for different purposes. Fast express trains, accommodation passenger trains (some of these latter running on mountain roads) and heavy freight were all included. From 25,000 to 35,000 miles, depending upon the character of service, was the average mileage before turning, and the general wear as taken from plaster casts was very good. The master mechanics handling the wheels have informed me that their behavior on the road or in the lathe in the machine shop was the same as that of an ordinary steel-tired wheel. We have lately started our works in Pittsburg, and during the last month from 900 to 1,200 additional wheels have been shipped and are daily being placed on the different roads.

MR. E. B. HALSEY:—What is the percentage of carbon used in the steel, and do you start from a blank or from blocks of steel cut from the ingot?

MR. LOSS:—The percentage of carbon is about .70, and the ingots are, as previously described, at present run separately. They are round, with varying thicknesses, and there is no doubt but what we shall shortly run them in multiples. Not being a mere steel casting, we use no sink-heads, but fall back upon the great pressures exerted upon the metal in the two presses and the rolling mill to solidify it. The pressure on the rim while rolled is equal to that existing in the largest tire-mill of to-day. The microscopic photographs show how well we have succeeded. It must be added, however, that a great deal of time and expense were bestowed on the subject of how to cast the ingots, resulting in the adoption of some very interesting methods. Our uniformity in product has been greatly advanced by this knowledge.

PRODUCTION OF ALUMINUM IN THE UNITED STATES IN 1902.

The production of aluminum in the United States during 1902 was approximately 7,300,000 pounds, as compared with 7,150,000 pounds in 1901, an increase of 150,000 pounds according to a report on the production of that metal by the United States Geological Survey. The Pittsburg Reduction Company, operating the Hall patents, continues to be the sole producer of aluminum in the United States, and, although the company is in patent litigation with the Cowles Electric and Smelting Aluminum Company, of Cleveland, its plants are being developed vigorously. It has in operation 11,000 horse-power at Shawinigan Falls, Quebec, a total of 16,000 horse-power, which is equivalent to a capacity of 4,500 tons of metal yearly, or more than the entire output of the rest of the world. The increased activity on the part of the company has been due to the fact that some of its fundamental patents will expire within a few years, and it is striving to perfect the methods employed to such an extent that after the expiration of the patents it will be in a position to compete successfully with new producers that may enter the field. Although the demand for aluminum has increased extensively, the price per pound continued practically stationary throughout the years 1901 and 1902. An international agreement between all of the aluminum producers has been drawn up and the price of ingot aluminum fixed for 1903, says the report. There are five companies in the world that produce aluminum at nine locations. For several years past the various companies have continued their secretive policy concerning the development of the industry, and practically nothing has been published in regard to modern improvements beyond the descriptions of patents, which have been granted mainly for the purification of bauxite—the chief raw material used in the manufacture of the metal.