I.

II.

SURVEY OF THE MAINTENANCE AND REPAIR OF A MODERN STEAM LOCOMOTIVE

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III.

TABLE OF CONTENTS

	Page
Introduction . . . . . ;	4.
Historical Review of Steam Locomotive	5.
Present State of the Steam Locomotive and the Repair Shop	10.
Personnel of the Motive Power Department	14.
Diagram of Line of Duty of Personnel of Maintenance & Repair Department	15.
The Repair Shop Departments	17.
Important Heavy Duty Repair Procedures	28.
Conclusions	31.
Bibliography	32.
Whyte's Classification of Locomotives	34.
Machine Shop	35.
Approval Sheet	36.

IV.

INTRODUCTION

The material contained in this treatise deals: first, with the advancement of the steam locomotive from the beginnings; second, with the present state of the steam locomotive and of the steam locomotive repair shops; third, with the personnel of the Motive Power Department of a modern steam railway; fourth, with the various departments constituting the repair shop; and fifth, with important heavy duty repair procedures.

The treatise differs from the mass of writing on the particular subject in that it does not enter into a detailed study of all the procedures and operations which necessarily take place in the repair of the steam locomotive. But, as indicated by the title, the reader is given a good general knowledge of the intricate workings which take place in the "roundhouse" and the "backshop" of our railway shops.

An acknowledgement of appreciation is hereby extended to Mr. T. W. Fulton, Southern Railway machinist, for his valuable assistance in the description of the various actual operations as they took place. Important observations of actual operations were carried out at the John Sevier and Coster Shops of the Southern Railway System with the kind permission of Master Mechanic F. C. Simpson.

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V.

GENERAL SURVEY OF FIELD

1.[1] HISTORICAL REVIEW OF THE STEAM LOCOMOTIVE

The first discoveries converning the use of steam for power purposes is not known, but as far back as one hundred years before the Christian era a machine, operated by steam, had been constructed by Hero at Alexandria, Egypt. No doubt, he understood the expansive power the the practical uses of steam.

Newton, in 1680, attempted the design of a machine whereby the reactionary force of steam upon air would propel a vehicle forward. Newton's attempt, as was Hero's, was unsuccessful. Nathan Read, of Salem, Massachusetts, in 1794 attempted the construction of a steam carriage. It was the first attempt of this nature in America.

Nine years after Read's experiments, Trevithick constructed a steam locomotive designed to run a cast iron tramway. He faithfully believed in the fact, which had formerly been disputed, that a smooth wheel acting on a smooth rail had the necessary adhesion to draw a load proportionate to the weight placed on the wheels and the power of the machine. He maintained that the boiler with its load would supply the weight. He employed saturated high pressure steam, and his engine contained all the essential features of the present-day locomotive; however,

(1) The Science of Railways, The Locomotive and Motive Power Dept., Books I and II, by M. M. Kirkman, p. 13 to 43.

it was found after the trial that the cost of operation exceeded the power output.

The practical developments of steam for locomotive use stood practically at a standstill until 1811 when John Blenkinsop employed Matthew Murray to construct a steam locomotive for use on Blenkinsop's tramway between Middleton and Leeds, Massachusetts. There were many severe grades on his three and one-half mile railway, and in consequence, a rack and gear attachment was used on the locomotive. This locomotive was very successful, and it continued in operation for some time.

At this time, George Stephenson, who has been called the father of the railway system, carried out experiments on the "Blucher". Stephenson was a mechanical engineer, and he possessed an unusual talent and an ability to impress others with the value of his conceptions. In 1825 Stephenson, who was then employed by the Stockton and Darlington Railway, put in service a locomotive of his own design. This locomotive was so successful that it continued in operation until 1841.

The first multitubular boiler locomotive was constructed in 1827 by Seguin, of France. He recognized the great possibilities of this type of boiler, and his efforts proved that the evaporating power of an engine was greatly increased by the multitubular principle.

The Stockton and Darlington Railway had eleven locomotives in successful operation during the year of 1830. As an indication of the success of the locomotive, one of

the eleven locomotives owned by the above company pulled 130 tons of coal on a level at the rate of five miles per hour. The driving wheels had a diameter of four feet, and the cylinders were eleven inches in diameter with a stroke of twenty inches.

The first successful type of locomotive in the United States was ordered from England in 1829, and during that year an event of note took place when the Liverpool and Manchester Railway held a competitive trial for the purpose of selecting a locomotive for use on its line. George Stephenson's "Rocket", which had been entered in the trials, was the officials' selection. Stephenson accordingly was awarded a contract for seven of his machines, and the locomotives were delivered the following year. They were rated at a speed of thirty-six miles per hour, and had incorporated in them an improved steam blast system.

In 1831, the Baltimore and Ohio Railroad offered a reward of four thousand dollars to the maker of the best American-built locomotive which would be of three and one-half tons weight and pull fifteen tons at fifteen miles per hour on level ground. This prize was awarded to Daves and Gartner, of Pennsylvania. This company built an upright boiler locomotive with a smoke stack of thirteen feet in height.

Many controversies sprang up at this time regarding the possibilities of six-wheeled drivers over four-wheeled

drivers. Ultimately, the great value of the six-wheeled type was universally recognized. Another controversy was the question of broad gauge and wide gauge track systems. The Great Western Railway introduced a gauge of seven feet, and maintained that the locomotive was capable of greater speed and uniformity ofoperation than the generally recognized gauge of four feet, eight and one-half inches. The four feet, eight and one-half inch gauge, however, was finally universally accepted as a standard gauge.

In 1847, a speed of seventy-nine miles per hour was attained by a locomotive of the London and Northwestern Railway. This locomotive had driving wheels with a diameter of eight feet and six inches, and they were probably the largest ever used on any locomotive. Records show that the engine evaporated three hundred cubic feet of water per hour and consumed a minimum of fuel of two and one-half pounds per horsepower per hour.

It is important at this stage to note that the American locomotive exceeded the English built engine in its ability to haul greater loads and at a higher rate of speed. This was due to the fact that the American locomotive had a large size boiler, higher steam pressure, and an enormous heating surface. These designs were incorporated because of greater distances, greater loads, and sharply curved tracks which the locomotives in this country had to overcome.

(2) From this period until the early nineties, the trend in locomotive design tended toward horizontal, multitubular boilers, smaller driving wheels, and other fundamental features which are incorporated in the finished engines of the present day. It is noteworthy that the earlier locomotives had cabs suspended between the engine frames. They were very narrow, being limited by the frame clearances. During the early nineties, some locomotives were constructed with the firebox foundation rings raised to the top of the frames and widened to the width between the driving wheels. This gave a substantial increase of grate area and heating surface. Later, the fireboxes were placed back of the rear driving wheels and widened to the entire width of the locomotive. This increase in length was accommodated by placing the rear end of the frame on a trailing truck having wheels of small diameter. Naturally, this type of firebox construction was limited only by the railway line clearances and the ability of the fireman to shovel coal.

The tendency toward larger locomotive sizes increased until recent years. Since the year 1910, however, the practice has been to limit the locomotive size, and to obtain greater capacity and efficiency by the application of such appliances as superheaters, mechanical stokers, and feedwater heaters. It is not within the scope of this paper to go into a detailed study of the construction and

(2) Locomotive Cyclopedia of American Practice, 1922, pp. 101

operation of each appliance on a locomotive; however, it is well to comment on the development of the valve. The slide valve was in common use until replaced about 1900 by the piston valve. Compound locomotives were extensively used until recent years; these were of the two-cylinder cross-compound type; three-cylinder compound type; or four-cylinder compounds of either the superimposed type or the tandem type. Quoting a report of the American Railway Association Committee on Locomotive Construction which states: "In early locomotives of the mallet type the 'D' slide valve was used on the low pressure cylinders. When used as pushing locomotives, there was no particular trouble experienced, but when these locomotives were employed in road service, cutting of the slide valves in the low pressure cylinders developed. The piston valve was then resorted to to overcome this trouble."

Since the experiments of Trevithick many different types of locomotives have been designed and constructed, but several types which proved to be most efficient have practically become standard in America. These types are of three general classes: freight, passenger, and switching locomotives.

2. PRESENT STATE OF THE STEAM LOCOMOTIVE AND THE REPAIR SHOP.

(3) In the first three quarters of 1937, domestic steam-locomotive orders totaled 166 for American railroads.

(3) Mechanical Engineering, Dec. 1937, p. 933-936.

The majority of these locomotives have four pairs of drivers, and capacities probably exceed 4000 i.h.p. Of these, the Hudson type engine has been most successful. The boiler carries 275 lbs. pressure, and is made of nickel steel. The total engine weight is 360,000 lbs. The weight on drivers has been raised from 5300 lbs. to 196,000 lbs., the tractive effort with 22½" x 29" cylinders is 43500 lbs. or 2.6 per cent more, and the booster, which is 11 per cent stronger than before, adds 12,100 lbs. or 28 per cent to the main engine. The factor of adhesion is 4.5 which is very high. The engine axles are equipped throughout with Timken roller bearings.

The nine Hudson-type locomotives ordered from the American Locomotive Company by the Chicago and Northwestern Railway are the most powerful locomotives under construction. They will have a tractive effort of 55,000 lbs. with 300 lbs. boiler pressure, 25" by 29" cylinders and 84 inch drivers. The five powerful 4-8-4 type (See Appendix, Table I), locomotives, built in 1937 for the Richmond, Fredricksburg, and Potomac Railway by the Baldwin Locomotive Works, have a tractive effort of 66,500 lbs., an adhesive weight of 277,250 lbs., a grate area of 96.3 sq. ft., 275 lbs. boiler pressure, and 5374 sq. ft. of evaporation surface.

The fourteen steamlined locomotives built by the Lima Locomotive Works for the Southern Pacific Railway have the distinction of being the largest streamliners in service.

They have a tractive effort of 62,000 lbs. in the main cylinders and 12,000 lbs. in the booster. All of these engines carry tenders of 20,000 to 22,000 gallon water capacity.

The Union Pacific Railway now has a streamlined Pacific-type locomotive in service with Timken roller-bearing rods. The Baltimore and Ohio, a President Class Pacific of 1927 for service between New York and Washington also has Timken equipped rods. A unique 4-4-4-4 type of high-powered passenger locomotive was built by the Baltimore and Ohio in 1937. To reduce parasite forces in the motion work, one pair of cylinders each has been placed front and back of the driving wheels and connected to two different axles. It carries 350 lbs. boiler pressure, a tractive effort of 65,000 lbs. is produced by the 18 x 26½ inch cylinders with only 89,000 lbs. piston thrust and 76 inch drivers. The engine weighs 391,550 lbs., the factor of adhesion is 3.70, and the maximum static axle load is 61,660 lbs.

The repair shops of the early railway systems were very inadequate. They possessed no elaborate equipment for the upkeep of the locomotives, but had only machinery which was available during the existing period. Moreover, the shops were not placed at the best strategic points on the systems; however, as the railroads gradually grew and expanded into the best systems of the present day, the shops accordingly expanded in order to cope with and

maintain the movement of the freight and passenger traffic.

To take a specific case, the Southern Railway System, which comprises a number of subsidiary railways throughout the South, has a number of major locomotive repair shops on the Southern Railway proper. These are located at Washington, D. C; Columbia, S. C.; Knoxville, Tennessee; Cincinnati, Ohio; Somerset, Kentucky; and Sheffield, Alabama. These shops are located over the entire system so as to serve efficiently the locomotives of each division. For example, the locomotive repair shops at John Sevier and Coster, Tennessee, serve the system north to Harriman, east to Bristol and Asheville, south and west to Chattanooga, and also other smaller branch points in all directions from Knoxville. As these various points are not at a greater distance than 125 miles from the repair shops, it may be seen that a locomotive at any point on the division does not have to be taken any great distance for repairing.

The particular repair works under consideration actually comprise two repair shops. The Coster Shops houses the boiler shop, an extensive machine shop, roundhouse, blacksmith shop, and other repair departments for cars. The John Sevier Shops houses a moderate size machine shop and roundhouse.

As may be expected, the railroads of the present day maintain the latest design in equipment, for it is to their advantage to do so because of the strict rules and

regulations specified by the Interstate Commerce Commission governing the safe operation of railway equipment.

3. PERSONNEL OF THE MOTIVE POWER DEPARTMENT.

The Motive Power Department is supervised by the Superintendent of Motive Power. He is directly responsible to the General Manager, and his duty is to supervise all maintenance and repair operations of equipment on the division assigned him. On an equal basis with him, is the Superintendent of Transportation. His duties are to maintain all passenger and freight traffic on the division, and he is also directly responsible to the General Manager. Among his many duties, the Superintendent of Motive Power is required to submit daily, weekly, monthly, and yearly reports of all repair operations, which take place in his department, to the General Manager. He is also required to maintain a sufficient force of skilled workmen for the repair of the company's equipment. This necessarily requires him to have a large number of office workers for the handling of the business.

Immediately below the Superintendent of Motive Power in the line of duty, is the Master Mechanic. He must be a thoroughly efficient and intelligent man, and he usually attains his position by working up through the ranks, thereby acquiring first-hand knowledge of the system of operations, familiarity with the vast number of machines, and an understanding of the workmen. He submits the various reports of operations to the Superintendent of Motive

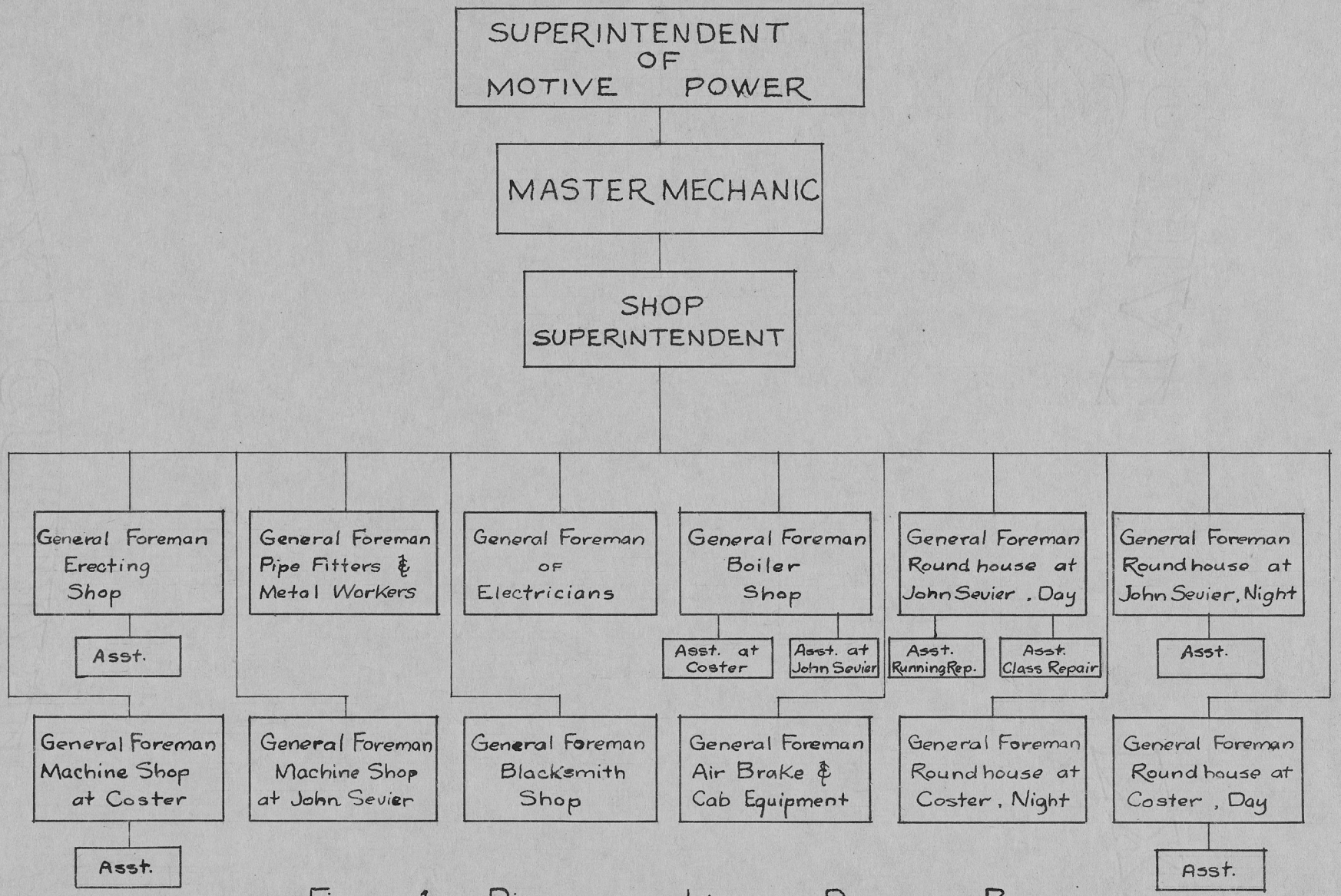

Figure 1. Diagram of Line-of-Duty of Personnel of Maintenance and Repair Department

Power. He receives inspector's reports, arranges them in a systematic order, and returns them to the several General Foremen; the reports which they receive covering only the work to be done in their particular departments.

Immediately under the Master Mechanic, is the Shop Superintendent. He is in charge of actual operations through his various General Foremen. Under his supervision, and directly responsible to him, is the General Foreman of the Erecting Shop, the General Foreman of Pipe Fitters, the General Foreman of the Machine Shop at Coster and the General Foreman of the Machine Shop at John Sevier, the General Foreman of Electricians, the General Foreman of Air Brake and Cab Equipment, the General Foreman of the Boiler Shop, and the two General Foremen of the Roundhouse, night and day duty at Coster, and the two General Foremen, night and day duty, at John Sevier.

The General Foremen have charge of actual repairs, and they must be fully experienced in their particular lines of work. These men usually obtain their positions through persistent hard work and an ability to cope with a situation with quick and clear thinking. They have able assistants who cooperate with them in completing their assigned jobs in the specified time.

The railroads, it may be safely stated, were chiefly responsible for the development of the apprentice system of workers. In each department there are a number of helpers and skilled workers. The helpers obtain their jobs by applying in the capacity of a helper. They are not

trained prior to their employment, but obtain their knowledge by helping a skilled man. Due to laws and regulations of the various labor organizations, the helper is not entitled to obtain promotion to the rank of a skilled worker. In order for him to become a skilled worker, he must relinquish his accumulation of age with the company as a helper, and become the youngest on the seniority lists of the skilled workers. The apprentice serves a four year training course, and then if conditions permit, he becomes a skilled worker with full seniority. (See diagram of Line-of-Duty of Personnel from Workmen to Superintendent of Motive Power - Figure 1.)

4. THE REPAIR SHOP DEPARTMENTS.

The repair shop comprises the following departments: the erecting shop; the pipe fitting and metal working shop; the machine shop; the blacksmith shop; the electrical shop; the air brake and cab equipment department;the boiler shop; and the roundhouse. These departments, as a unit, maintain the locomotives in the running conditions as required by the Interstate Commerce Commission.

Taking the departments in order, the erecting shop is located in a large building, commonly called the "backshop". A number of tracks run the entire length of this shop, which is approximately 400 feet wide and 700 feet in length. Two 250 ton overhead traveling cranes run the entire length of the shop. These two cranes, operating as a unit, are able to hoist an entire locomotive. Pits,

some 7 feet in depth, are located under the parallel tracks in order for workmen to perform any necessary operation on the under carriage of the locomotive. In general, the operations performed in the erecting shop include: dismantling locomotives for frame repair, boiler repair, cab repair, and wheel repair; complete general overhaul; and erecting of locomotives after all necessary repairs have been completed.

The pipe fitting and metal working shop is located in the backshop under the same roof with the erecting shop.

Working out of this shop are a number of skilled pipe-fitters who are thoroughly familiar with their assigned duties. There is a vast system of pipes and fittings which go into the building of a locomotive and this system of piping must be constantly inspected and maintained in first class order. The piping system comprises both steam and water fittings, and a great expense is incurred in the constant supply of these necessary materials.

The metal workers are thoroughly familiar with their duties which consist of heat treating certain parts to a required degree of hardness and working certain parts to a required shape or size. These workers are not concerned with the pouring of castings into required shapes and sizes, as the castings are usually ordered from such locomotive building works as Baldwin or the American Locomotive Works. Located in the black-smith shop, which is

essentially the metal working department, is a number of heavy and light duty steam and air hammers, forges, and rolls, and other necessary metal working tools which are used for the shaping of the various parts.

The electrical shop, essentially, is a secondary shop as regards to the repair of the locomotive. This shop, which is supervised by the Electrical Foreman, maintains the headlights, safety lights, cab lights, and the turbo-generator equipment. Quoting a ruling of the Interstate Commerce Commission issued in 1915 and made effective in 1920, Rule 129 and 131: "Locomotives used in road service between sunset and sunrise shall have a headlight which, under normal weather conditions, will enable persons, with normal vision, in the cab of the locomotive, to see a dark object the size of a man for a distance of 1,000 feet or more ahead of the locomotive. If required to run backward for any portion of the trip, except to pick up a detached portion of the train or in making terminal movements, a light which will meet the foregoing requirements shall be placed on the rear. Locomotives used in yard service between sunset and sunrise shall have two lights, one located on the front of the locomotive and one on the rear, each of which, under normal weather conditions, will enable persons, with normal vision, in the cab of the locomotive, to see a dark object the size of a man for a distance of 300 feet or more."

The incandescent lamps are used with a 500-watt

turbo-generator capable of developing 32 volts and full load at a steam pressure of 100 lbs., the governor to regulate the speed of turbine properly between steam pressure range of 100 lbs. minimum and 250 lbs. maximum without the necessity for change of nozzle or governor parts. The turbo-generator is located as near the cab as practicable, usually set longitudinally with the boiler, on the left-hand side, with generator end toward the locomotive cab.

The air brake and cab equipment repairs are supervised by a General Foreman. Every employee whose duties are connected in any way with the maintenance and operation of the air brake are examined from time to time as to his qualifications for such duties by the Inspector of Air Brakes or other person appointed by the proper authority, and a record is kept of such examination. The locomotive brakes may be used with, or independently of, the train brakes without regard to the position of the locomotive in the train. They may be applied with any desired pressure between the minimum and the maximum, and this pressure will be automatically maintained in the locomotive brake cylinders regardless of leakage and of variation in piston travel until released by the brake valve. Equipment which is necessary for the satisfactory repair of the air brake equipment is at the command of the workmen.

The boiler shop is a part of the erecting shop, and is supervised by a General Foreman and an Assistant. The

operations carried out include: repair of leaks; replacement of defective staybolts; repair of crown sheets; and repair of all other defective appurtenances of the entire boiler and firebox. Locomotive boilers as used in American practice are of the internal firebox, straight fire tube type. The general type of boiler is constructed with a cylindrical shell containing the fire tubes or flues, an enlarged back end for the fire box,and an extension front end, or smokebox, leading out from which is the stack. Boilers are classified by their shape as straight top, having the cylindrical shell of uniform diameter from the firebox to the smokebox; as wagon top, having a conical or sloping course of plates next to the firebox and tapering down to the cylindrical courses; as extended wagon top, having one or more cylindrical courses between the firebox and the sloping course which tapers on the top and sides to the diameter of the main shell; as conical type, having one or more cylindrical courses between the firebox and the sloping course and a conical connection course which tapers to the diameter of the main shell.

In the usual design, the sides and the top or crown of the firebox transmit the heat of the fire to the water, and there is an excessively active generation of steam near these parts. The front or forward sheet of the firebox has a large number of holes in which the ends of the fire tubes or flues are inserted. These tubes carry the

products of combustion to the smokebox, and, as they are surrounded by water, give up a large amount of heat to the water from the waste gases passing through them. In general, they are built of steel plate, but copper plates have also been applied to fireboxes in some countries.

The roundhouse is one of the most important subdivisions of the maintenance department. If a locomotive has been found defective on the inspecting pit, it is placed on one of the several tracks in the roundhouse. Pits are located under these tracks in order for the workmen to perform duties requiring access to the undercarriage. The "pits" in the roundhouse take care of two classes of repair; running repair and heavy duty repair.

The General Roundhouse Foreman with an assistant is in charge of the roundhouse. A number of machinists are employed who make necessary repairs such as: replacing and repairing of springs; dismantling the undercarriage for wheel repairs, cylinder and piston repairs, and all other types of running gear repairs. They also perform such repairs on the boiler as cleaning of flues and welding of cracks and leaks.

The Machine Shop comprises the largest subdivision of the maintenance department. A smaller shop is located at the John Sevier Shops and is supervised by a General Foreman and an assistant. There are many different types of machine tools used in the machine shops, and probably none are employed more extensively than lathes. Machines of this

class, being particularly adapted for turning cylindrical surfaces, are used for turning axles, wheels, tires, crown brasses, crank pins, piston and valve rods, bushings, packing rings, and for cutting screws, etc.

The cutting of threads on staybolts, studs, screws, pipe and other locomotive parts requires the use of special attachments for lathes or milling machines. Where the amount of such work will warrant the regular use of a machine for thread cutting alone, specially designed power-driven machines equipped with proper threading dies are commonly employed. These special machines are generally a modification of the lathe.

Boring machines are made in two general classes: vertical and horizontal; they are used not only for boring but very often the vertical machines are used for turning cylindrical, flat, and tapering surfaces and the horizontal type for drilling, milling, and facing. In the vertical boring mill, the part is held to the table either by clamps or in a chuck secured to the table; the table revolves and the tools remain stationary, except for the feeding movement. The horizontal type of boring mill is used principally for boring, drilling or milling, and also for turning or facing flanges or similar surfaces when such an operation can be performed to advantage in connection with other machine work on the same part.

Milling machines are widely used for finishing large castings or forgings having flat surfaces. These surfaces

are milled by a circular cutter having a number of teeth or cutting edges on its lower face or base which cut away the metal as the cutter rotates; at the same time the cutter being fed automatically over the work in the required direction. In some milling machines provision is made for rotating the cutter horizontally; in other types, the cutter rotates about a vertical axis. They are called horizontal or vertical milling machines as the type of design indicates.

Planing machines are used in locomotive repair shops for finishing flat or plane surfaces on many of the larger locomotive parts. Planers are made in several different types, but in general the design consists of a long bed or base having ways on which is placed a plate or table which travels under a tool fixed to a cross-rail secured to housings. A tool slide on the cross-rail provides for transverse movement of the cutting tool.

The shaper is adapted for work similar to that performed by a planer, but is used for smaller work because it is less cumbersome to handle and quicker in its movement. Shapers are made in several different types; the column shaper, having a vertical column or frame which supports the ram, work table, and driving mechanism; the crank shaper, which may also be a column shaper geared; the rack shaper, the ram driven through gearing and a rack attached to the ram; the draw-cut shaper, cutting when the tool is moving toward the column of the machine; the traverse

shaper or traversing-head; and the open-side shaper. Horizontal, vertical, or angular surfaces may be planed in a shaper in practically the same way as in a planer; the tools used are similar in form to planer tools but are smaller. The work may be held in a vise, or clamped to the table which is provided with slots for receiving clamping bolts.

The slotting machine is used for finishing slots or other enclosed parts which could not be planed by the tool of a horizontal machine like a planer or shaper. It is also used for other classes of work requiring flat or curved surfaces which can be machined to better advantage by a tool which moves vertically. The slotting machine operates on the same principle as a shaper except that the ram which carries the planing tool moves in a vertical direction and at right angles to the work table. This type of machine is extensively used in locomotive shops.

Drilling machines of both the vertical and horizontal designs are extensively used in railroad shops. These machines may have a single spindle or multiple spindles, and may be of the upright or radial types. Multiple-spindle drilling machines are equipped with more than one drilling spindle which permits drilling a number of holes simultaneously. With this type of machine all the different tools necessary can be inserted in the various spindles, and the work done by passing the part from one spindle to the next. By this method, holes of different diameters can

be drilled and counterboring or remaining operations performed without changing tools provided the machine has enough spindles to hold the tools needed for each particular part of the work.

Grinding machines for use in railroad shops for general purposes and for special classes of work have reached a high stage of development. They are now being used for accurately finishing work which formerly was done in a machine equipped with a cutting tool, and have taken the place of such tools to a considerable extent. Some of the types in use are: Cylindrical grinders of the external and internal designs; surface grinders of various designs; and special machines designed for the grinding of locomotive and car wheels.

The shearing and punching machines used in machine shops for cutting steel plates, cutting off bars and other materials, and for punching rivet holes, etc., are made in many different designs. A shearing machine of the ordinary type is equipped with a lower fixed blade and an upper blade attached to a ram or other device to which vertical movement is imparted by the driving mechanism. The shear blades vary in form, depending on the character of the work.

Power hammers are used in the repair shop for general forging operations. They are made in many different types adapted to particular classes of work. They may be divided into two general classes: those actuated by a crank or eccentric which imparts motion to the hammer head

through some form of mechanism designed to give the required springing action; and those operated either by steam or compressed air.

The forming or flanging of plates in locomotive and car construction, and the bending and pressing of other shapes, as well as the removal or application of wheels from axles, bushings from rods, etc., requires the use of many different machines. Usually they are operated by either pneumatic or hydraulic pressure. These machines are made in various different designs, among which are the portable pneumatic flanging machine, and stationary hydraulic presses for forming and pressing wheels on or off the axles, and they are made in various designs of single or double end machines.

It is well to mention the great value of the portable machine tools. These are made in many different designs for use in locomotive repair work. Their use makes possible the re-boring of worn cylinders and valve chambers, re-facing of cylinders, domes, etc., and truing worn crank pins without dismantling the locomotives in order to take the parts to a shop for machining. These portable tools include boring bars; planing, turning, and milling machines; pipe bending machines; flue cleaners; and other special purpose machines.

These descriptions include the majority of the major and important machine tools found in the locomotive repair shops. In the appendix, Table II, will be found a list of

- the major operations, class of work, and the machines used in performing the work as carried out in the machine shop.

5. IMPORTANT HEAVY DUTY REPAIR PROCEDURES

After completing a run, the locomotive is placed on Pit No. 1 where a qualified inspector or machinist inspects the running gears, driving gears, spring rigging, injectors, and other necessary appurtenances. This inspection is carried out according to Interstate Commerce Commission specifications, and the inspector is required to submit a report of his findings to the Master Mechanic. Also carried out according to government specifications, is a complete inspection of the boiler. This includes: inspecting of the grate; inspecting of the interior of firebox, regarding faulty staybolts, arch, and flues; and inspecting of the exterior of the boiler, regarding barrel and firebox steam leaks.

If found defective, the locomotive is then placed on a pit in the roundhouse where machinists dismantle necessary rigging for preforming such repairs as re-boring of worn cylinders and valve chambers, re-facing of cylinders, domes, etc., truing worn crank pins, cleaning flues, repairing spring rigging, and repairing other necessary breakdowns using portable machines and tools. If the breakdown requires complete dismantling, the locomotive is placed in the Erecting Shop. First, the main rods and those parts of the valve mechanism which would interfere with the work are removed; thus enabling the wheels to be

removed. This is accomplished by lifting the boiler and its attached parts by the overhead traveling cranes. When the boiler is raised, the wheels are rolled out, or the boiler is moved to another position and placed on blocks and jacks. The boiler, frame, cylinders, and cab are removed if the nature of the repairs require it. It is usually necessary to remove the cab when extensive repairs are required on the firebox.

All parts requiring repairs are placed in a bath of hot water and lye in order to remove the grease and dirt. After being removed from the lye bath, the parts are thoroughly washed and then inspected. The necessary repairs are noted, and the number of the engine to which the different pieces belong is stamped on each part,or a tin tag is attached to them so that they can be identified.

If the wheels require repair, they are taken to the wheel shop, placed in a lathe and a new contour turned on both tires simultaneously. If the tires are worn to the minimum of thickness, they must be removed from the wheel centers and replaced with a new tire previously turned and bored to fit the centers. Tires are bored with a slightly smaller diameter than the wheel centers and then heated and shrunk on. The tires are removed from the wheel centers by heating the entire circumference of the tire, causing it to expand sufficiently to permit its removal. The journals and the crank pins are then trued up or replaced with new ones and the wheels are then ready for use.

If the boiler requires repair, the exterior sheets are removed and the boiler-makers replace defective stay-bolts, flues, and repair any type of leak or crack in the barrel and firebox. Defective grates are also repaired or replaced.

Wear on the interior walls of the cylinders, due to the piston travel, causes a shoulder to form at each end which must be removed by boring. This work may be done by using a portable boring bar without removing the cylinders from the boiler; however, if the cylinders require other repairs necessitating their removal, the work is done on a lathe.

If the reboring of a cylinder makes only a slight increase in its diameter, it may be compensated for by replacing the piston rings with others of large diameter. If the diameter has been considerably enlarged, a liner or bushing is inserted. The bushing is then bored to the desired size.

Practically all locomotives in use today are equipped with piston type valves. As in the case of the main cylinders, the reciprocating motion of the piston causes the formation of shoulders at the ends of the stroke; however, as valve chambers are provided with bushings which receive the wear, it is only necessary to re-bore or renew the bushings.

VI.

CONCLUSIONS

The preparation of material, actual observations, and use of advice given by interested parties tended to make this treatise a most helpful and interesting investigation. As the reader now realizes, the subject of locomotive maintenance and repair constitutes an immense field for study. The lines along which the Maintenance Department is operated cannot be altered unless great expense is incurred; however, the scheduling and routing system now in use in some of the major railway repair shops could be more effective if introduced and enforced in all shops of the American Railways. The railways are more closely interrelated than the majority of industrial concerns; therefore, any condition affecting one, affects the entire system. However, disregarding minor faults, the labor unions and efficient personnel tend to make the railroads the most efficient division of American industry.

VII.

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VIII.

APPENDIX

TABLE I

WHYTE'S CLASSIFICATION OF LOCOMOTIVES

SYMBOL	WHEEL ARRANGEMENT	TYPE
0-4-0		4-Wheel Switcher
0-4-2		
0-4-4		Forney 4-Coupled
0-4-6		6-Wheel Switcher
0-6-0		Yard Service
0-6-2		
0-6-4		Forney 6-Coupled
0-6-6		
0-8-0		8-Wheel Switcher
0-8-2		
0-10-0		10-Wheel Switcher
2-4-0		
2-4-2		Columbia
2-4-4		
2-4-6		
2-6-0		Mogul
2-6-6		
2-6-4		
2-6-2		Prairie
2-8-0		Consolidation
2-8-2		Mikado
2-8-6		
2-8-4		
2-10-0		Decapod
2-10-2		Santa Fe
2-12-0		Centipede

WHYTE'S CLASSIFICATION (CONTINUED)

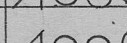
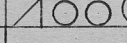
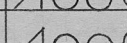
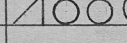
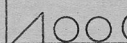
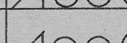
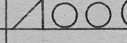
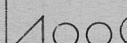
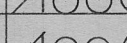
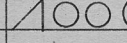
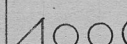
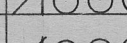
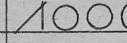
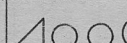
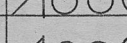
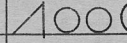
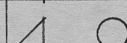
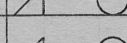
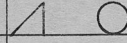
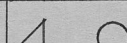
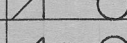
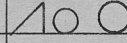
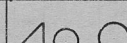
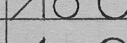
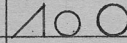
SYMBOL	WHEEL ARRANGEMENT	TYPE
4-2-2		Bicycle
4-4-0		American
4-4-2		Atlantic
4-4-4		Reading
4-4-6		
4-6-0		10-Wheel
4-6-2		Pacific
4-6-4		Baltic
4-6-6		
4-8-0		12-Wheel
4-8-2		Mountain
4-10-0		Mastodon
0-4-4-0		Mallet Artic.
0-6-6-0		Mallet Artic.
0-8-8-0		Mallet Artic.
2-4-4-0		Mallet Artic.
2-4-4-2		Mallet Artic.
2-6-6-0		Mallet Artic.
2-6-6-2		Mallet Artic.
2-6-8-0		Mallet Artic.
2-8-8-0		Mallet Artic.
2-8-8-2		Mallet Artic.
2-10-10-2		Mallet Artic.
2-8-8-8-2		Mallet Artic. (TRIPLEX)
2-8-8-8-4		Mallet Artic. (TRIPLEX)
4-4-6-2		Mallet Artic.

TABLE II
MACHINE SHOP

CLASS OF WORK	MACHINE TOOL	OPERATION
DRIVING WHEELS & TIRES	1-80" Driving Wheel Lathe	Turning Tires
	1-Driving Wheel Lathe	Trueing Journals
	1-7' Vertical Boring Mill	Boring Tires
	1-400 Ton Wheel Press	Smoke Arch Rings
	1-Quartering Machine	Quartering Wheels
	2-Vert. Boring Mills, 6 and 7 Feet	Wheel Centers
AXLES	1-Lathe, 32"x14'	Driving Axles
	1-Double Keyway Cutter	Cutting Keyways
	1-Lathe, 26"x14'	Engine Truck Axles
	1-D.H. Axle Lathe	Tender Truck Axles
CRANK PINS	1-Lathe, 26"x10'	Crank Pins
	1-Vert. Drill, 36"	Crank Pins
		Guide Bars
		Guide Blocks
		Crossheads
		New Crosshead Shoes
CYLINDERS & HEADS	1-Cylinder Boring Mill	Bore Cylinders
	1-Cyl. Planer, 72"x12'	Plane Cylinders
	1-Port Miller	Mill Ports
	1-Radial Drill, 5'	Cylinders
		Wheel Centers
		Front Frame Rails
	1-Vert. Boring Mill, 42"	Piston Packing Rings
		Front Cylinder Heads
		Back Cylinder Heads
	1-Vert. Rapid Prod. Lathe, 37" Bullard	Piston Value Bushing
		Piston Value Packing Rings
PISTON RODS	1-Lathe, 26"x12'	Piston Rods
	1-Gap Grinder, Norton	Piston Rods
	1-Cottering Machine	Keyways
GUIDES	1-Plane Horiz. Miller, 20"x8'	Guides
		Old Guides
	1-Guide Bar Grinder, 80"	Guides
	1-Shaper, 16"	Cut to length, Cut clearance
		Old Guides, Cut Clearance
		Guide Blocks
		Frame Keys
	1-Lathe, 16"x8'	Guide Blocks
		Crank Pin Collars
		Wrist Pin Washers
VALVES	1-Planer, 30"x10', D.H.	Values
		Value Yokes
		False Seats
	1-Plane Miller, 14"x6"	Values
		False Seats
		Value Strips
	1-Lathe, 20"x10',	Value Yoke
	1-Lathe, 24"x14'	Piston Values

IX.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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