INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE DIVISION OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE SOUTHERN RAILWAY NEAR HOFFMAN, ILL, ON JUNE 7, 1915

SEPTEMBER 14, 1916

To the Commission

On June 7, 1915, there was an accident to a freight train on the Southern Railway near Hoffman, Ill, which resulted in the death of the engineman and the injury of the fireman After investigation as to the nature and cause of this accident, I beg to submit the following report

This part of the Southern Railway is a single-track line No block signal system is in use, trains being operated by time table and train orders Where the accident occurred the first marks were on tangent track at a point about 400 feet beyond the end of a curve to the left of three degrees, this curve being 1,200 feet in length Approaching this curve the track is straight for a considerable distance It is laid with 75-pound rails 33 feet in length, with about 20 white oak ties under each rail, well ballasted and maintained The weather was clear

Eastbound extra 1056 consisted of locomotive 1056 and a caboose, in charge of Conductor Chamberlain and Engineman Cato It passed New Baden, the last open telegraph office, at 4 15 a m, and at 5 20 a m, when near Hoffman, about 25 miles beyond New Baden, the left main driving wheel came off, resulting in the engine being stripped on both sides The engineman was killed by being struck by a broken side rod The accident occurred while the train was traveling at a speed of about 25 miles an hour

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Examination of the track showed that the first marks were on the ties on the outside of the left hand rail, from 10 to 20 inches from the gauge side of the rail These marks appeared at intervals of from 10 to 30 ties, and apparently were made by a broken connecting rod About 80 feet beyond the first of these marks there was quite a large hole in the ground, apparently made by this broken connecting rod The first mark on the right side of the track was on a tie on the outside of the rail at a point about 33 feet beyond the first marks on the opposite side, and was about 10 inches from the gauge side of the south rail At a point about 800 feet beyond the first marks, there were marks on the ties on the outside of the right rail where the main driving wheel on that side had bounded against the ball of the rail, continuing to do so from this point to the point where the locomotive stopped, about 1,300 feet beyond the first marks When the locomotive stopped it was found that the main driving axle was broken on the left side With the exception of the two main driving wheels no other part of the locomotive was derailed

Locomotive 1056 left St Louis, Mo, on June 6, at 9 45 p m, hauling passenger train No 1 and was in charge of Engineman Miller Engineman Miller stated that he noticed the locomotive pounded badly, and on arrival at Cooper, 13 1 miles from St Louis, he found that the left main driving box cellar had come down, making the engine pound, and also striking the eccentric strap He was unable to block the cellar up and sent word to the yard at Denverside, about 6 miles from St Louis, for another locomotive Engineman Cato had locomotive 658 in readiness to leave on second-class train No 73 and was instructed to take his locomotive to Cooper and turn it over to the engineman of train No 1, bringing locomotive 1056 back to the Denverside shop, which he did The driving box cellar was put in place, the locomotive was then coupled to a caboose, and departed from Denverside at 3 20 a m, with orders to run extra to Shops, near Princeton, Ind, 162 6 miles from St Louis It was on this trip that the accident occurred

Conductor Chamberlain stated that upon taking charge of locomotive 1056 at Cooper he and Fireman Summers tried to pry up the cellar, while Engineman Cato was under the engine in readiness to insert the bolts to hold it in place They were unable to repair the engine, however, and after getting orders proceeded back to Denverside The hostler then took the locomotive to the roundhouse Orders were later issued for this locomotive to be ready to double head on passenger train No 23 Engineman Cato said that it would not take over 30 minutes to fix the locomotive, and then called up the roundhouse on the telephone and on asking how long it would take was told that it would take about 30 minutes unless the cellar was broken, to which Engineman Cato replied that he did not think it was broken, at least he had not discovered any break Conductor Chamberlain stated that in a short time they were called for duty, and on going to the office for running orders he found locomotive 1056 standing in front of the office with Engineman Cato in readiness to proceed After receiving orders, the extra proceeded, the first stop being at Miller, 20 4 miles from St Louis, where an opposing train was met The stop at this point was of 10 or 12 minutes duration, and Conductor Chamberlain stated that while there the engineman did some work on the engine, he did not know what it was, but supposed that it was the ordinary work at stopping points He said, however, that he heard Engineman Cato remark about the locomotive riding roughly At Germantown, 42 1 miles from St Louis, a stop was made for water, but he did not get out of the caboose and did not know whether or not Engineman Cato did any work on the locomotive at that point Approaching Posey, 52 9 miles from St Louis, the engineman sounded the whistle and a proceed signal was given, as the extra then had 14 minutes in which to go to Hoffman, a distance of 4 7 miles, and clear the time of passenger train No 2 Conductor Chamberlain stated that the first he knew of the accident was when he heard the noise occasioned by the breaking down of the locomotive, the accident occurring while the train was traveling at a speed of about 25 or 30 miles an hour On examining the locomotive he found the main driving wheel axle broken on the left side, inside of the journal box He further stated that he did not smell any hot metal and had not at any time noticed anything wrong

Head Brakeman Martin verified the statements of Conductor Chamberlain, and added that at Miller Engineman Cato remarked about the locomotive pounding and the flanges cutting, and he saw the engineman oil the main driving-wheel flanges At Germantown Brakeman Martin left the caboose and walked to the locomotive He stated that when he reached there the engineman was oiling on the left side, and that when he reached the right side he oiled the main driving-wheel flange again, and said that he believed the axle was bent, and that he did not think it would hold together until they reached their destination

Flagman Lemond stated that at Miller the engineman remarked about the pounding of the locomotive, and said that the flanges were cutting, and he oiled the main driving-wheel flanges He stated that he did not leave the caboose at Germantown and did not know what the engineman did at that point

Fireman Summers stated that when they took the locomotive at Denverside after it had been repaired Engineman Cato oiled the flanges of the driving wheels, as they were cutting Engineman Cato said that the locomotive seemed to lead to the right, and that they could not make a fast run, but would take their time When en route to Miller the locomotive was pounding, and while both of them thought that something was wrong, they did not know what it was Fireman Summers said that at Miller Engineman Cato looked over the locomotive and then came back to the caboose, where he had gone to look at a time card, and told him that the cellar was down again Both of them returned to the locomotive, and the engineman said that he believed the axle was bent Fireman Summers then asked him if he could detect a bent axle by running slowly and watching it, and Engineman Cato replied that he did not think he could Fireman Summers further stated that at Germantown he was busy at the waterspout and did not hear the conversation between Engineman Cato and Brakeman Martin When the extra had reached a point about 1¼ miles west of Hoffman Engineman Cato shut off steam At this time Fireman Summers was sitting on the seat box on the left side, and he saw the collar from the left front side rod flying through the air He then got down on the deck of the locomotive, but when the locomotive commenced to swing he thought it was going to turn over, and he got off on the right side, at the same time saying to the engineman that he had better get off

Hostler LaGrange stated that he handled locomotive 1056 from Denverside to the roundhouse and return In going to the round house he hauled it with a switching locomotive, but on the return trip he handled it under its own steam, and he stated that it acted as if the valves were out of adjustment and that there was also a grinding noise He called Engineman Cato's attention to it and they secured a torch and looked over the locomotive, but could not find anything wrong, and Engineman Cato said that he supposed that it was on account of the locomotive being dry, and gave it an oiling

Night Roundhouse Foreman Nelling at Denverside, stated that a message was received that a driving box cellar was down on locomotive 1056 and that repairs were to be made and the locomotive made ready for service Later on, another message was received to have the locomotive ready as soon as possible, and he then talked over the telephone with Engineman Cato, and said that the engineman told him it would not take 10 minutes to get the cellar up as they had nearly gotten it up themselves He then inquired if the journal box was not hot and the engineman replied that it was not The locomotive was then placed on the ash pit, instead of over the pit in the machine shop as he had intended, and the cellar was put in place and packed Foreman Nelling stated that he had no notice from any one that there was anything else wrong, and that he inspected the locomotive with Tank Repairer Weiss and found nothing wrong

Tank Repairer Weiss stated that when locomotive 1056 arrived at Denverside he crawled under it and examined the cellar to see if it was broken It had a strong compression spring which held it on the binder and held the grease up against the journal He then pulled the compression plate down and tipped the cellar, but could not see anything wrong with the journal and told Foreman Nelling of the condition existing He stated that he then put the cellar up and repacked it, the locomotive being held only about 20 minutes while this work was being done

Master Mechanic Johnson, located at Princeton, stated that the engine was shopped at Princeton on March 28, and released on March 31 No other repairs had been made on this locomotive except such running repairs as are made in the roundhouse He further stated that the axle which broke was not applied at the Princeton shops and on account of having no marks on it, he was unable to say when or where it had been applied, but he thought from the amount of wear on the journals that it had been in this locomotive four or five years

This accident was caused by the breaking of the main driving-wheel axle on locomotive 1056 The investigation to determine the reason for the failure of this axle was conducted by Mr James E Howard, engineer physicist, tests being made in conjunction with representatives of the Southern Railway at the shops of that company at Alexandria, Va The report covering the results of this investigation is as follows

REPORT OF THE ENGINEER PHYSICIST

The cause of the failure of the main driving axle under engine No 1056 was an area of metal at the surface of the journal which contained chatter marks and short incipient cracks made by the roughing cut in the lathe during the machining of the forging from which the axle was made At one place only along the length of the journal were these incipient cracks in evidence, and at that place the line of fracture had its origin This condition represented a defect in the machine finishing of the axle The finishing cut in the lathe did not remove the metal which had been injured by the roughing cut

The mechanical fit of the hub of the left-hand driver was confined to a small part of the length of the wheel seat of the axle This led to the formation of a number of fractures starting in the axle in the wheel seat, which were necessarily obscured from view by the hub These fractures were in an advanced stage of development when complete failure at the journal occurred Incidentally, but not bearing upon the failure of the axle, it may be remarked that two groups of holes, 1 inch in diameter by 1 inch deep each, were drilled and plugged, representing an error in the location of two keyways in the middle portion of the axle

The axle in question was not the original one used under engine No 1056 Its dimensions did not conform to those called for on a blue print said to represent the original axle There were no marks of identification upon it, and nothing is known of its history prior to the occurrences connected with this derailment It was made, quite evidently, from an untreated, solid, steel forging, and was finished turned throughout its length

Figure No 1 shows the shape and dimensions of the axle, on which are entered notes descriptive of the examination which was made of the metal

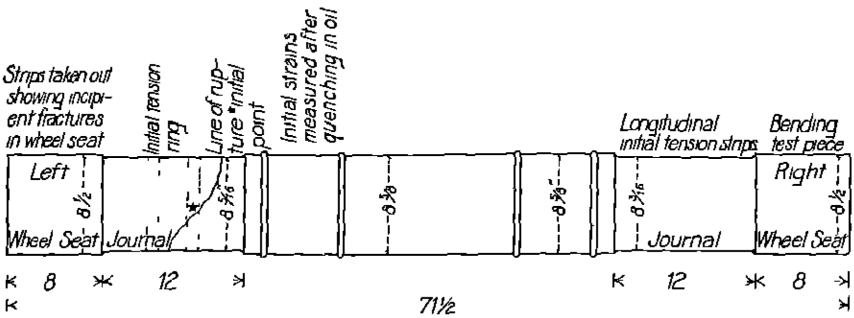

FIG No 1—Sketch of main driving axle which failed under engine No 1056 showing location of fracture in left hand journal with descriptive notes concerning tests and positions of test pieces

The line of rupture started at a place in the periphery, about 5 inches from the inner end of the journal, indicated by a star on the sketch of the axle, thence taking an oblique course, ultimately separating the axle The fracture was progressive, according to the evidence presented by the ruptured surface It appeared to have developed gradually until about one quarter of the cross section was separated, after which the remaining stages of rupture were rapidly completed

Figure No 2 is an end view of the fractured surface, on which is also placed a star to indicate the incipient point of rupture Two drilled holes in the fractured surface are shown by the figure, where chips of the metal were taken for chemical analysis

Figure No 3 shows the appearance of the surface of the journal in the vicinity of the incipient point of rupture The illustration is about twice natural size The shattered condition of the surface of the metal, attributable to a heavy roughing chip in the lathe, is shown by this illustration These short cracks penetrated the metal depths of two to three hundredths of an inch They were made more pronounced in appearance, as here illustrated, by bending the metal which opened the cracks somewhat

Heavy machine tool cuts tear the metal and also introduce internal strains There is a close resemblance in the effect of such heavy tool cuts to shearing and punching effects, if, indeed, they are not of the same order Shearing and punching of steel is very properly prohibited in certain specifications It is important that equivalent effects be avoided which may result from using lathe and planer tools with heavy cuts and feeds

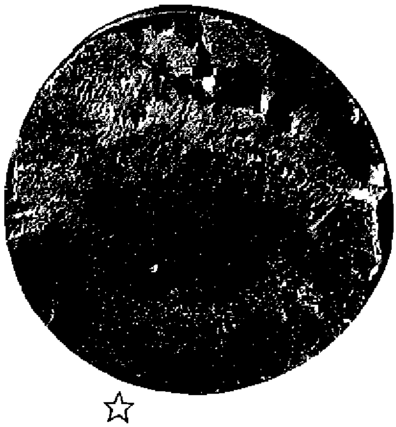

FIG No 2—End view of fractured surface of journal Incipient point of rupture indicated by a star

The effects of taking heavy cuts with machine tools will again be referred to in another part of this report dealing with tests made upon a heat treated axle which failed in service after a comparatively short period of time

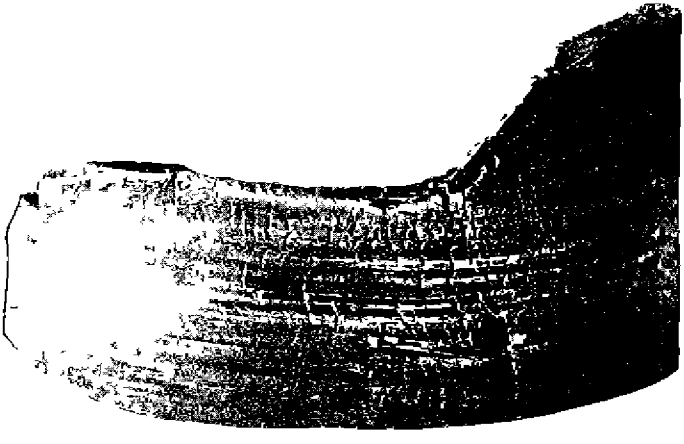

FIG No 3—Appearance of the surface of the journal near incipient point of rupture

The limited area of bearing surface of the hub of the left hand driver on the wheel seat of the axle was a notable feature It ranged in length from $1\frac{3}{4}$ inches down to $\frac{1}{2}$ inch only This zone of contact was near the outer end of the axle, $1\frac{3}{4}$ inches distant from it Beyond this zone in either direction there was some looseness of the wheel on the axle The location and irregular shape of the bearing surface on the wheel seat is shown by Figure No 4

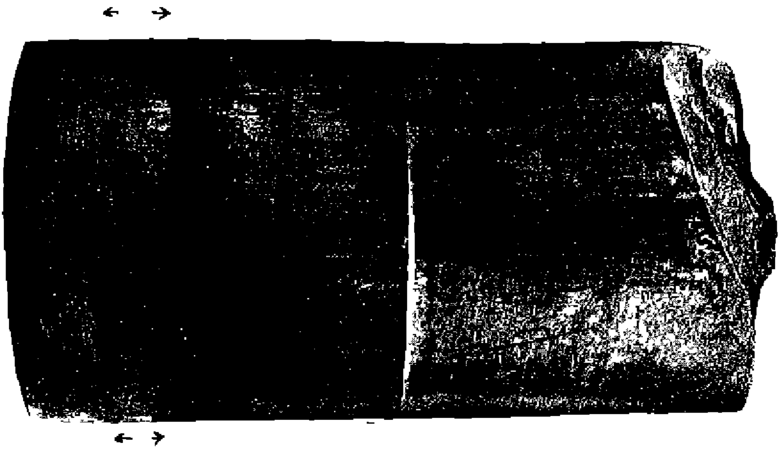

FIG No 4—Side view of broken axle showing oblique surface of fracture, also the limited length of bearing which the hub of the driver had on the wheel seat Length of bearing indicated by the witness marks on the illustration

Circumferential cracks were visible on the surface of the wheel seat at and near the inner border of the bearing surface These cracks ranged in length from $\frac{1}{2}$ inch to $2\frac{1}{2}$ inches, in all aggregating about one half the circumference of the axle Figure No 5 represents a segment of the wheel seat, showing the width of the bearing surface of the hub at this part of the axle, also the location of two fractures, one near the zone of bearing of the hub and the other near the inner end of the wheel seat, in close proximity to the journal The length of bearing surface here was from $\frac{1}{2}$ inch to $\frac{15}{16}$ inch long One fracture had a depth of $\frac{1}{4}$ inch, the other fracture, near the journal, had a depth of 1 inch and a circumferential length of 2 inches

Figure No 6 shows some of the fractures which were in process of development in the left hand wheel seat, which would undoubtedly have extended and caused complete rupture of the axle had not the fracture of the journal taken place The axle was in a critical state in this part of its length

An examination of the right-hand wheel seat showed the hub of the wheel had a bearing over substantially its full length A bending test of a strip of metal from this wheel seat showed good bending properties and did not display the presence of any incipient cracks in the steel.

An initial tension ring, so called, was taken from the left hand journal just outside of the line of rupture. The internal strains in the surface metal of the journal were those of tension. In a tangential direction the tensile stress corresponding to the mean strain of two diameters was 5,300 pounds per square inch. The presence of tensile strains at the surface of the journal is accepted as evidence that the metal had not been cold rolled for finishing purposes, or, if so, with very little effect, since the usual rolling, to smooth the journal, puts internal strains of compression in the surface metal. A deep cut and heavy feed in machine tooling is competent to introduce strains of tension in the surface metal; therefore, the evidence furnished by this initial tension ring is consistent with the indications furnished by the chatter marks that such a cut had been taken during the fabrication of the axle.

Longitudinal strips were taken from the surface metal of the opposite journal. The internal strains at that end were of compression, one strip showing a strain equal to 4,500 pounds per square inch, another from the opposite side of the journal showing 8,400 pounds per square inch.

A tensile test of the metal, with a 2-inch longitudinal specimen 0.492 inch diameter, from the metal near the surface of the left hand wheel seat, showed an elastic limit of 45,260 pounds per square inch, tensile strength 79,470 pounds per square inch, with 27 per cent elongation and 40.5 per cent contraction of area. The metal showed a silky fracture.

FIG. NO. 5.—Segment of fractured axle, showing limited length of bearing of hub of driver on wheel seat; also location of incipient fractures in two places on wheel seat. Length of bearing surface of hub indicated by witness marks on the illustration.

The chemical analysis of the steel was as follows Carbon, 0.44, manganese, 0.95, silicon, 0.19, sulphur, 0.015, phosphorus, 0.03

Locomotive 1056 had a 10 wheel engine The weight on the drivers was 116,875 pounds, which gives a wheel load of 19,479 pounds, diameter of drivers, 72 inches

FIG No 6—Segmental pieces taken from axle left hand wheel seat showing incipient fractures ranging in depth from 1/8 to 1 3/8

A section, about three feet long, from the middle of the length of the axle was heated to a temperature of 1,550° F and quenched in oil A hole 1.9 inches diameter had previously been drilled through the axis of the piece Tangential and longitudinal strains were measured, representing those introduced by the sudden cooling of the metal

A violent disturbance of the metal occurs when it is suddenly quenched from high or even moderate temperatures Momentarily the surface metal, or that first quenched, is thrown into a state of tension, which is immediately reversed and a state of compression is set up as the interior cools The internal forces which are induced in the heat treatment of steels at this stage of the process are very great These forces at times are known to cause rupture during the violent and rapid changes in temperature which attend quenching Partial annealing, or drawing the temper, as generally called, ameliorates the intense state of strain which exists after sudden quenching While it is generally held to be undesirable to heat suddenly a large mass of metal, that is, to avoid charging cold metal in a hot furnace, nevertheless the reverse process of sudden cooling is that which is adopted in heat treatment

It might be expected that some apprehension would arise concerning the possibility of incipient fractures being introduced by the operation of quenching, spontaneous rupture taking place This apprehension is in fact shown in certain specifications which require a shock test to be made of heat treated axles to detect whether interior fractures have not been made by the process, thereby impairing the strength and safety of the axle

The final state of internal strain in quenched axles which have had their temper drawn will be of lesser magnitude than the temporary state of strain which prevailed at the time of quenching The steel, however, has had to pass through this severe ordeal and an inquiry into the conditions which attend the process require an examination of the state of strain caused by the quenching

From the present axle, after quenching in oil from the temperature of 1,550° F , a disk $\frac{7}{16}$ inch long was taken from the end first to enter the oil bath, facing off about 2 inches in length to get beyond the effect of quenching across the end of the piece Concentric rings were cut from this thin disk and the strains which they displayed were measured and their corresponding stresses computed The accompanying table shows the results obtained

Initial strains in metal of axle after heating to 1 550° F and quenching in oil

TANGENTIAL STRAINS IN CONCENTRIC RINGS FROM DISK TAKEN FROM AXLE NEAR LEFT HAND JOURNAL

Ring	Diameter approximate	Strains released—		Mean	Corresponding stresses
		Diameter A	Diameter B		
	Inches	*Inches*	*Inches*	*Inches*	*Pounds per square inch*
1	8 08	0 0103	0 0103	0 0103	36 200 compression
2	7 09	0035	0044	00395	10 710 compression
3	6 09	— 0010	— 0017	— 00135	6 650 tension
4	5 08	— 0037	— 0036	— 00365	21 550 tension
5	4 09	— 0033	— 0036	— 00345	25 300 tension
6	3 09	— 0009	— 0009	— 0009	8 730 tension
7	2 10	0030	0035	00325	46 400 compression

LONGITUDINAL STRAINS IN STRIPS TAKEN FROM SURFACE OF AXLE NEAR MIDDLE PART OF ITS LENGTH BEYOND POSITION OF THE ABOVE DISK

	Strains released	Corresponding stresses
	Inches	*Pounds per square inch*
Strip A	0 0190	57 000 compression
Strip B	0182	51 600 compression

The strains were measured on two diameters Two of the rings, Nos 1 and 6, displayed strains of the same amount on each diameter The greatest variation was shown by ring No 2, one diameter of which showed an expansion of 0 0009 inch more than the other

The results of the strains and stresses measured in the longitudinal strips are entered in the table with the tangential results

Figure No 7 shows the manner of cutting the disk into concentric rings and graphically illustrates the stresses which were displayed by each

It will be observed that the internal strains in a tangential direction were of compression at the exterior of the axle and next the bored hole, while the interior portion was in a state of initial tension

The stress of compression in the exterior ring was 38,200 pounds per square inch, and in that of the ring at the bore 46,400 pounds per square inch The maximum tensile stress observed in one of the interior rings, No 5, was 25,300 pounds per square inch These values represent the mean stresses in rings three sixteenths inch in thickness The range in tangential stress, of tension and compression, is shown to be 71,700 pounds per square inch

The longitudinal specimens, taken from the surface of the axle near the middle of its length, showed strains of compression, the stresses corresponding thereto being 54,600 and 57,000 pounds per square inch, respectively The strips were from opposite sides of the axle Necessarily some of the interior elements were in a state of initial tension to balance the compressive stresses at the surface The present observations were not extended to cover the determination of the longitudinal tensions in the interior of the axle The magnitude of these internal stresses can not but excite interest

The momentary state of tension endured by the exterior of the axle at the time of quenching left visible effects The drilled holes comprising the two groups of six each were permanently distorted In a tangential direction these holes were permanently elongated about 0 03 inch each Lengthwise the axle their diameters remained substantially unchanged The plugs which were inserted with driving fits were loosened in the holes

Figure No 8 shows the appearance of the axle at these two groups of drilled and plugged holes

The failure of this axle presents an additional example of the necessity of securing workmanship of a high order in the machine finishing and fitting of material which is exposed to such situations as those which are occupied by axles, that is, where repeated alternate stresses of tension and compression constitute the work which the steel is required to perform The demands which are made upon the steel are of a more exacting order in axles than experienced by metal not exposed to reversed stresses Conditions which do not seem to have pronounced influence on the primitive strength nevertheless are the direct precursors of failure in metal exposed to long continued stresses The magnitude of the stresses in the service of axles is somewhat indeterminate From the nature of the work done they are subject to wide fluctuations and without doubt on some occasions reach very high fiber stresses

A heat treated axle which failed in service was examined in conjunction with the axle which failed under engine No 1056 The heat treated axle was branded 11–14 It failed in service in October, 1915 It was the main driving axle of a Mikado type of engine, having jour nals 11 inches diameter by 22 inches long The weight on the drivers was 227,500 pounds, which if evenly distributed would give a wheel load of 28,437 pounds The diameter of the drivers was 61 inches The mileage of the engine at the time of failure was 30,904

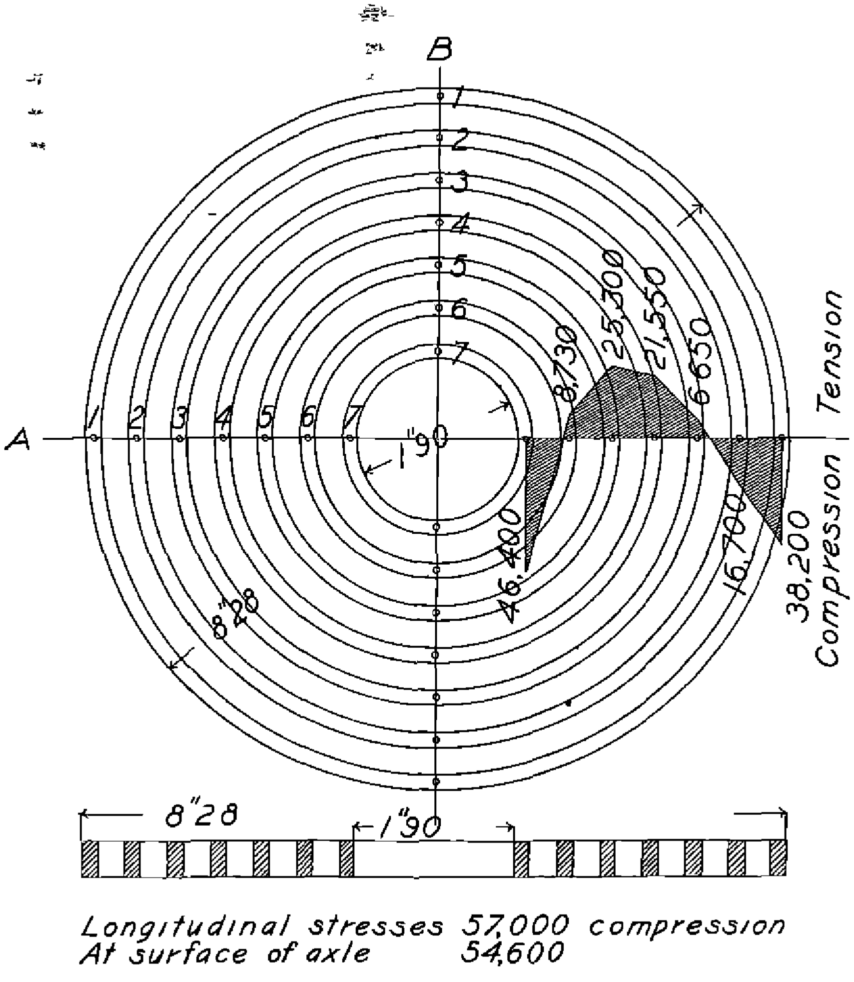

FIG No 7—Showing the manner of taking out concentric rings from disk after the axle had been quenched in oil from a temperature of 1550 F graphically illustrating the initial strains which were found in the rings by shaded zones

Fracture occurred at the middle of the length of the axle, taking an oblique course through the metal of the short section between journals The engine was run 210 miles, without its train, after the break was discovered In consequence of this run the fractured ends were much bruised, obliterating all evidence of the initial point of rupture

The examination of this axle was for the purpose of measuring the internal strains remaining in the steel after heat treatment and its term of service, also strains introduced by cold rolling with a hardened steel roller as used in finishing the surfaces of journals, strains after heavy and light chips were taken off the axle in a lathe and planer, and those resulting from peening the surface Strains were measured in both tangential and longitudinal directions There were bending tests of the metal of concentric rings which were taken out, in the lathe, from the section of the axle adjacent to the fractured surface After cutting apart radially, the metal of these rings was bent outward, straightening them and also reversing the curvature

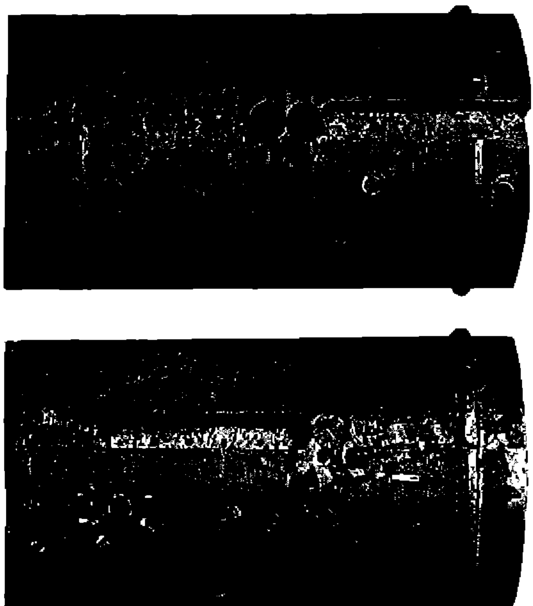

FIG No 8—Showing two groups of six drilled and plugged holes each in middle part of axle The plugs were loosened at the time of quenching the axle in oil

Figure No 9 is a sketch of the half of the axle which was examined, on which are indicated the positions of the several rings on which the internal strains were measured

Referring to the initial strains which were present in the axle, in the condition it was found after its fracture the metal at the surface of the rough turned section between journals was in a state of tangential compression The metal of ring A, an exterior ring from this rough turned section, showed an expansion in diameter corresponding to 13,000 pounds per square inch compression Ring B, located in the same plane as ring A, but taken five eighths inch below the sur face of the axle, showed the stresses of compression were there reduced to 8,360 pounds per square inch

Ring C, corresponding in position to B, in respect to depth below the surface of the axle, was turned off on its outer surface, using a rough machine-tool cut The strains displayed by this ring were negligible, whence it appeared that a heavy machine tool cut had modified the initial strains which existed in that position, the effect being to efface strains of compression, bringing the metal to a state of repose, practically free from internal strains It will be noticed also in other instances that the effect of turning off the metal with a heavy cut in the lathe has a tendency to put the metal into a state of tension, a tendency the reverse of certain other kinds of treatment which introduce strains of compression

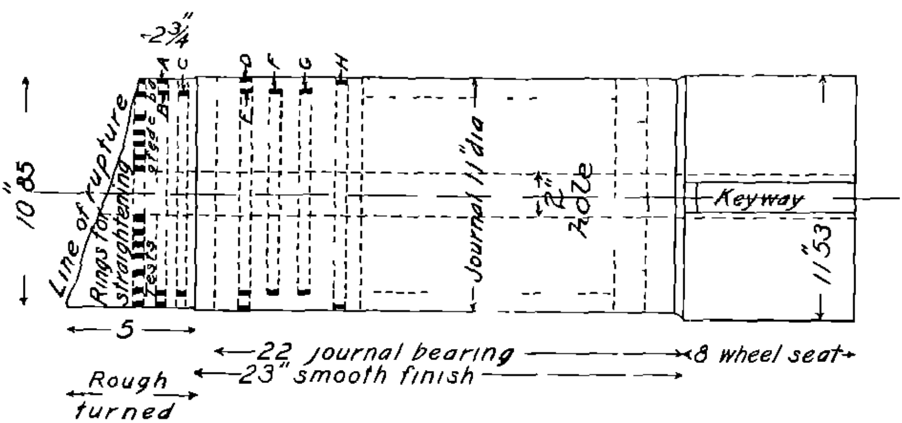

FIG No 9—Sketch of the half of the heat treated axle which was examined showing positions of rings on which initial strains were measured and those used for bending tests

The next ring to be examined, marked "D," was taken from the journal portion of the axle, this being a surface ring The tangential stress at this place was found to be 20,390 pounds per square inch compression The tangential stress in ring E, 1⅜ inches below the original surface, in the same plane as ring D, was reduced to 11,080 pounds per square inch compression The initial strains measured on the inner rings represented those which remained after the removal of the outer metal There is a readjustment of the internal strains whenever a change in the dimensions of the axle takes place, hence these interior values represent a condition which existed after the more highly strained surface metal had been removed The results were sufficiently pronounced to indicate that a reduction in the intensity of the strains existed at successive depths below the surface

Additional rings differently treated were taken from the same depth as ring E, admitting a direct comparison to be made between the original condition of the metal at this depth and the modified strains which were introduced by special treatment.

Ring F, taken from the same distance below the surface as ring E, was cold rolled with a hardened steel roller, in the manner in which it is customary to finish the surfaces of journals. The rolling gave the surface a high polish. The initial stresses were by this process increased to 14,540 pounds per square inch compression.

Proceeding along the length of the axle, the next ring, G, of the same depth below the surface as before, was rough turned on its exterior surface. The feed of the lathe tool was 6½ per inch, with a depth of cut of ⅛ inch. The effect of this rough cut was to reverse the initial stresses of compression and put the metal into a state of tension.

The normal state of the metal at this depth, as shown in ring E, was in compression, with a value of 11,080 pounds per square inch, which was reversed in the present ring to a state of tension having a value of 12,076 pounds per square inch. These modifications in the internal strains are of significance. They represent stresses of such magnitude that they do not admit of being ignored. The scope of these results is such as to show that internal strains may be of compression and that they may be reversed and put into a state of tension.

Finally, ring H was taken out, the surface of which was peened. A light chip was first taken from the surface of the journal and the metal then peened with a light hand hammer. This ring showed a state of initial compression, the stress amounting to 21,100 pounds per square inch.

In the tables which next follow are grouped the results which were obtained on the heat treated axle. In one table the tangential strains, and their corresponding stresses appear, while in the other the longitudinal strains and stresses are shown.

Initial strains and stresses corresponding thereto in heat treated axle marked 11–14

[Determinations made on one half of axle after it had fractured in service near the middle of its length between journal portions]

TANGENTIAL STRAINS AND STRESSES

Marks	Description	Strains released	Corresponding stresses
		Inches	*Pounds per square inch*
A	Taken from rough turned section of axle portion between journals outer ring from surface of axle	+ 0046	13 000 comp
B	Taken from rough turned section of axle portion between journals inner ring ⅜ inch below surface	+ 0026	8 360 comp
C	Taken from rough turned section of axle portion between journals, inner ring from position corresponding to B A rough cut with lathe tool taken over the exterior of this ring	+ 0001	Negligible
D	Outer ring from journal surface of axle	+ 0073	20 390 comp
E	Inner ring from journal	+ 0035	11 080 comp
F	Inner ring from position corresponding to E The surface of this ring was finished by rolling in the same manner journals are rolled to give them a smooth polished finish	+ 0046	14 540 comp
G	Inner ring from position corresponding to rings E and F A rough cut with lathe tool, taken over the exterior of this ring	− 0038	12 076 tension
H	Surface of journal turned off to 10 75 inches diameter then surface of this ring peined with light hand hammer	+ 0075	21 100 comp

LONGITUDINAL STRAINS AND STRESSES IN STRIPS TAKEN FROM THE JOURNAL

1	Strip taken at the surface of journal	+ 0111	33 300 comp
2	do	+ 0095	28 500 comp
3	Medium rough cut taken off surface of strip in planer	+ 0002	600 comp
4	Heavier cut than taken off surface of strip 3	− 0017	5,100 tension
5	Strip taken off after heavy turning cut in lathe	− 0001	300 tension
6	do	− 0007	2 100 tension

Tensile tests made with longitudinal specimens, ½ inch diameter by 8 inches long, which were taken from the journal portion of the axle, gave the following results

Location	Elastic limit	Tensile strength	Elongation	Contraction of area
	Lbs per sq in	*Lbs per sq in*	*Per cent*	*Per cent*
Outside	44 600	92 700	27	51 2
Middle	49,200	91 100	26	53 1
Inside	44,600	92,600	8 5	8 8

Appearance of fracture

Outside	80 per cent cup granular	Middle	66 per cent cup granular	Inside	100 per cent full granular

Chemical analyses

	Carbon	Manganese	Silicon	Sulphur	Phosphorus
Outside	0 58	0 84	0 218	0 046	0 039
Middle	56	85	194	045	041

The metal of an axle is exposed to severe conditions while in service, and stresses which are incident to service conditions should not be augmented by internal strains of fabrication if they are found to be detrimental It has been customary, apparently, to consider only those stresses in axles which were due to the external loads coming from the weight of the engine, or cars, as the case happened to be The internal strains at the time of quenching, during heat treatment, those which result from heavy machine cuts in rough turning, and those which accompany the operation of cold rolling the journals for finishing purposes appear to attain a magnitude comparable to the direct stresses which are caused by the wheel loads

The internal strains which have been referred to in connection with the heat treated axle were those having a tangential direction The longitudinal strains claim rather more attention since the failure of an axle commonly occurs by tension in a longitudinal direction

The tests were continued, ascertaining the longitudinal strains which were present at the surface of the journal Two strips, taken diametrically opposite each other, showed the surface metal to be in a state of initial compression, one strip having a value of 33,300 pounds per square inch, the other 28,500 pounds per square inch

Necessarily, certain parts of the axle are exposed to longitudinal strains of tension to balance those of compression which *are located at the surface In the heat treated section of the axle* which caused the Hoffman accident there was shown a state of tangential tension in the intermediate zone of metal, between the exterior metal and that which was exposed to the quenching action of the oil at the surface of the bore It was also shown that coincident *surface strains of compression existed in* the quenched metal in both tangential and longitudinal directions This condition in an axle, in which the surface metal is in a state of compression while the interior is in tension, is analogous to the state in which the head of a rail is found After cold rolling in service strains of compression are introduced at the running surface, increasing such as were acquired during cooling at the time of fabrication These longitudinal strains of tension in the interior of the axle furnish a contributory cause of interior cracks reported as having been witnessed in heat-treated axles. They are essentially of the same order as the reverse strains of compression in the tops of the heads of rails which lead to the formation of transverse fissures of interior origin. The influence of the exterior metal when in a state of compression is the same, whether in an axle or in a rail, in respect to putting certain of the interior elements into a state of tension. The effect of internal strains may very properly be taken into account when considering the causes of the premature failure of heat-treated axles.

Further tests were conducted on longitudinal strips taken from the journal portion of the heat-treated axle. A medium rough cut was taken lengthwise the axle by a planer tool. The initial strains in this strip were found to be only 600 pounds per square inch compression, a negligible quantity. A heavier cut was taken in the planer, over another strip, which resulted in putting the metal into a state of tension, the stress corresponding thereto being 5,100 pounds per square inch.

It was considered desirable to duplicate these observations on other strips the surface of which had been rough turned in the lathe instead of being planed. Two such strips were examined, one of which appeared to show a contraction of 0.0001 inch, a negligible quantity, the other contracted 0.0007 inch, which latter strain corresponds to 2,100 pounds per square inch tension.

These determinations show the control which, in a degree, can be exercised over the introduction of internal strains by variation in machine tooling. In modern machine practice efficiency has been the watchword, and a great stride has been taken in the rapidity with which it is possible to conduct machine operations. To guard against the effect of too heavy machine cuts, sufficient metal must be left after rough turning, on such important members as axles, to permit the finishing cuts to remove all seriously affected metal.

In general, there is a progressive change in the intensity of the initial strains in passing from one zone to another in the depth of the metal. It follows that the results here recorded represent mean strains and not the maximum intensity of effect which the steel endures. The results are therefore conservative statements of the strains which were in the metal.

Several rings from the heat treated axle were cut apart radially whereupon the ends closed in or sprung apart, according to the progressive character of the internal strains in the metal. Figure No. 10 shows the amounts which different rings changed their shape when further opportunity was given them to experience relief from the residual strains which were in the steel.

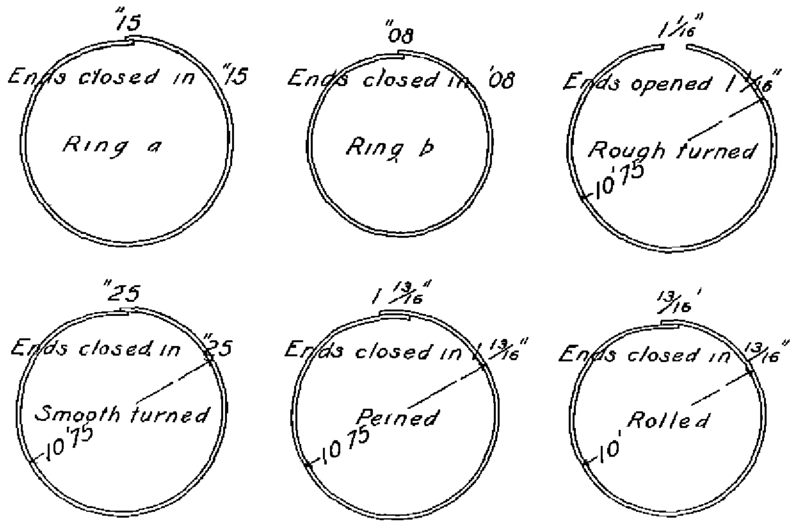

FIG No 10 —Sketches of rings from heat treated axle showing changes in shapes when cut apart radially caused by different treatment of their exterior surfaces when they were an integral part of the axle

In conclusion, it appears that the failure of the axle which occurred under engine No 1056 was caused by defective metal at the surface of the journal, arising from mechanical injury to the steel, done in the rough turning of the axle The incipient point of rupture was located in the area of affected metal at the surface of the journal, where numerous short cracks were present and attributable to the roughing cut of the lathe tool in turning the forging from which the axle was made While the direct cause of the fracture of the axle was due to the defective metal of the left hand journal, other fractures were in progress in the wheel seat of the same end of the axle which eventually would have resulted in complete rupture in that section These incipient cracks, which owed their formation to the imperfect fit between the hub of the left hand driving wheel and its seat on the axle, had extended in the aggregate a distance equal to one half the circumference of the axle Evidence of lack of care in the preparation of the axle was shown by the two groups of drilled and plugged holes representing errors in locating the key ways

SUMMARY

The evidence presented in the investigation of the failure of the axle under engine No 1056 conclusively shows that the workmanship in machining the axle was the prime cause of its failure There was an area of metal on the surface of the journal which showed short and numerous cracks clearly attributable to the roughing cut taken in the lathe, the effects of which did not turn out in the finishing cut

These surface cracks afforded the opportunity required for such a concentration of stress as led to ultimate failure The location of the place of rupture was an unusual one, being near the middle of the length of the journal, where the stresses in service would not ordinarily attain their maximum intensity The presence of the surface cracks explains why rupture occurred at this unusual place

It further appears in the investigation conducted by the engineer physicist that other fractures were in progress which eventually would have resulted in the failure of the axle These additional fractures were located in the metal of the wheel seat, on the left hand end of the axle While the length of the hub of the driving wheel was 8 inches, the length of bearing which it had on the axle ranged from only ½ inch to 1¾ inches The starting of incipient cracks in the wheel seat was doubtless influenced by this imperfect fit An error was made in laying out the keyways, and two groups of holes were drilled and plugged in consequence All of this evidence is derogatory to the class of workmanship needed in an axle These facts concerning workmanship, however, would not be known after the engine had been assembled and put out onto the road, but which nevertheless were the precursors of its ultimate failure

The quality of the steel of which the axle was made is not held responsible for the failure Its examination, apart from the defects due to workmanship which the metal itself was in no wise responsible for, showed no connection between its failure and the quality of the steel Its structural condition as regards initial strains showed a state of repose and comparative freedom from strains of magnitude in greater degree than the heat treated axle which was examined, in quest of correlated data, in conjunction with it

Primarily, inspection should be made in the shop and assurance of good workmanship received before an axle is in the first place assembled in an engine, and in view of the grave consequences which sometimes follow and are likely at all times to follow the failure of an axle, any indication of a defective condition should be fully explored and the cause of such trouble ascertained before further movements of an engine are made, and those movements which are essential to get the engine to a place of repair should be made with caution

There was warning given of impending failure when the engine was removed from the passenger train which it was hauling and replaced by another engine Trouble was located in the oil-box cellar, but search was not continued sufficiently to ascertain why there was trouble with the cellar The functions of the oil box cellar are such that the real seat of trouble should be looked for in other parts of the mechanism, and the inspection not confined to the cellar alone Had the inspection been more thorough and complete, it is probable that the real trouble would have been discovered and the accident averted, notwithstanding the defective workmanship which was shown to have existed

Respectfully submitted

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