SWINDON ENGINEERING SOCIETY.

TRANSACTIONS, 1906-7

INTERMEDIATE MEETING.– Tuesday, February 19th, 1907.
Chairman – Mr. A. H. Nash.

" LOCOMOTIVE CRANKS AND AXLES,"

BY

RODON. L. BURGE   (Member).

[The Author of this paper, finding that no notes on the subject exist in
the transactions of the Society, hopes that the following remarks may
be of interest.]

STRAIGHT AXLES.

The ordinary straight axle is of one general type. It will be seen from
Fig. 1 that there are no sharp angles where the diameter of the axle
alters, but that all alterations of diameter are made gradually by means of
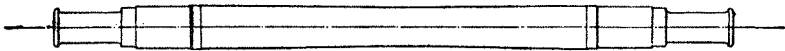a small curve or radius.   The constant breakage of axles in the early
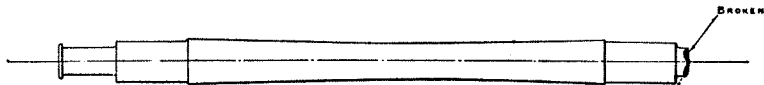

Fig. 1.

Fig. 2.

days of railways has been the cause of special attention being drawn to
the subject, which is one of much consequence, not only in axles but in
all parts of structures exposed to great vibratory or reciprocating strains.
In the case of railway rolling stock, both wheels are fixed to the axle,
and when travelling round a curve the outer wheel (unless the two cir-
cumferences be unequal) revolves too slowly or the inner wheel too fast.
The difference of speed is, therefore, made up by the wheel slipping
on the rail, thus producing some torsional strains on the axle.   There

is also a great amount of sliding sideways in consequence of the axle not being radial to the curves. It will be seen, therefore, that an axle has to be made strong enough to withstand strains other than its ordinary load.

An axle, however, may be too stiff and too strong, thus causing extra strain and shock to be thrown upon it, which would probably lead to its failure. Cases are not unknown of axles breaking in consequence of their being too stiff. It has been found that by reducing
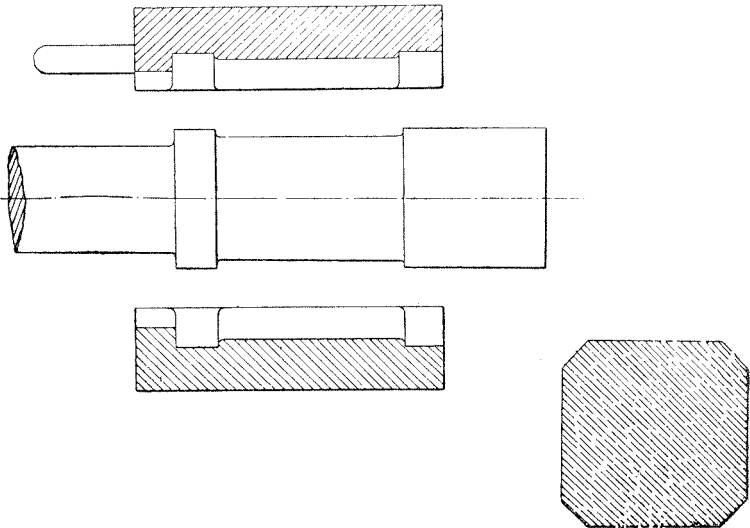

Fig. 3.

their diameter at the body, and giving them more elasticity, the possibility of breakage has been reduced to a minimum. The old type of straight axle was made with a collar, which was intended to reduce the side-thrust, but this method was found to be unsatisfactory, as fractures occurred at the collar. The modern practice is to have a straight journal without the collar, which seems to give better results. Axles were at one time made smaller within the bosses of the wheel (*i.e.*, the wheelseat), than behind the backs of the wheels, but in recent practice the axle is made of the full size, or slightly larger within the wheel than elsewhere, in order that there may be no hindrance or obstruction to frequent examination of the axle at a place where fractures are liable to commence.

Manufacture of Straight Axles.— Straight axles are usually made from blooms about 5′ 0″ long, 10″ square, with round corners, one end rounded to about $9\frac{1}{2}''$ in diameter and cut off in swages, the neck and collar are then stamped in a pair of swages, as shown in Fig. 3, the middle being hammered down, leaving about $\frac{1}{4}''$ for turning. In some works the blooms are rolled to the rough section in a cogging mill. In all cases the axles are worked at two heats, one half of each axle being finished before the other is commenced, either by swages or fast hammer blocks.

CRANK AXLES.

Several serious accidents having occurred through the crank axle of an engine breaking whilst the train was in motion, engineers have had to carefully consider the advantages of engines with inside cylinders and crank axles as compared with outside cylinders and straight axles ; of steel axles as compared with iron axles ; and of cranks hooped with iron bands as compared with cranks having the additional strength provided by an increase of metal in the webs of the crank itself. Although a crank axle is usually considered to be weaker than a straight axle, there appears to be no proof that this is the case in practice, and if the various strains on a crank are properly worked out they are found to be less than a force which would be sufficient to fracture a straight axle of the same diameter.

Different Kinds of Crank Axles.— There are several different kinds of axles, but in the early railway days straight web cranks seem to have been the most popular, probably because they were easy to manufacture. They are in use still on several railways. On the G.W.R. there are seven different kinds of cranks. " Fish-webbed," " taper," " oval," " straight," " circular," " elliptical," and " built-up." The elliptical type is used to a great extent on this line, but the built-up crank is now superseding it.

G.W.R. crank axles with taper webs (Fig. 4) have attained long lives and high mileage. These cranks, which were of iron, had small journals, and seldom fractured ; some are in use at the present day. This type of crank axle was also used on early Metropolitan engines with the addition of hoops (see Fig. 5). They were found to fracture chiefly in the inside journal, close to crank web.

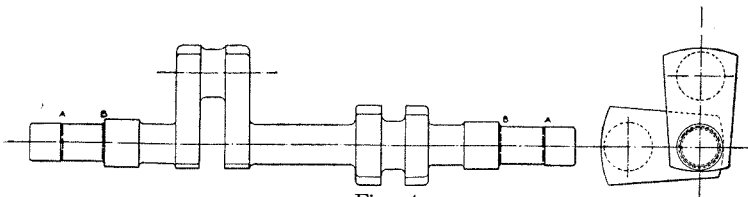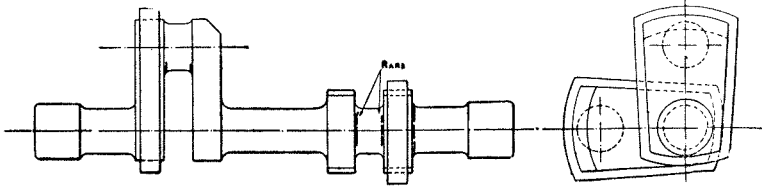Fish-bellied webs, such as used on the G.W.R. standard single-framed goods engines Nos. 2301-2500, fracture chiefly in the inside journal,
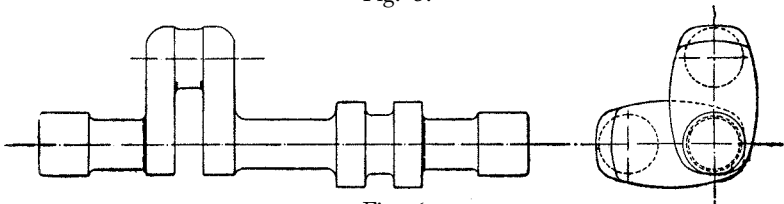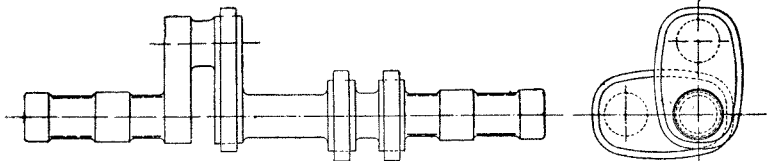
Fig. 4.

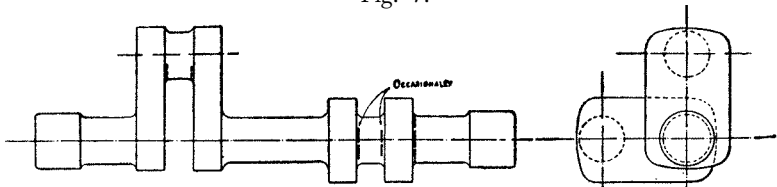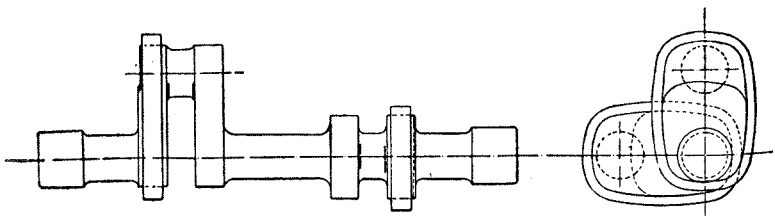Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.— G.W.R. $\dfrac{0.6.0.}{T}$ and $\dfrac{2.4.0.}{T}$

NOTE.— Thick lines indicate where fractures usually occur.

and occasionally circumferentially. (See Fig. 6.) These are very good cranks and do a good mileage. The same type of crank, is, with hooped webs, used on G.W.R. engines Nos. 1660-1700 (Fig. 7).
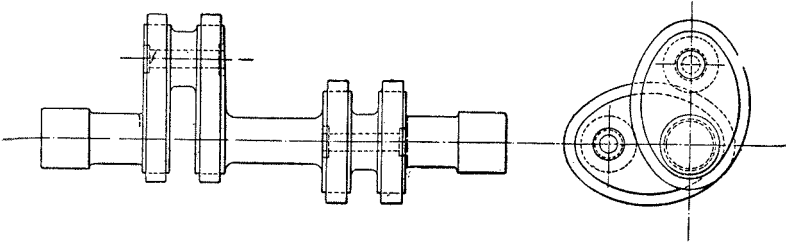

Fig. 10.

The journals wear small and taper, probably due to underhung springs. The hoops are left off to clear the pump. Fig. 8 illustrates a crank with straight webs, which is used on the G.W.R. Wolverhampton $\frac{0.4.2.}{T}$ class engines.
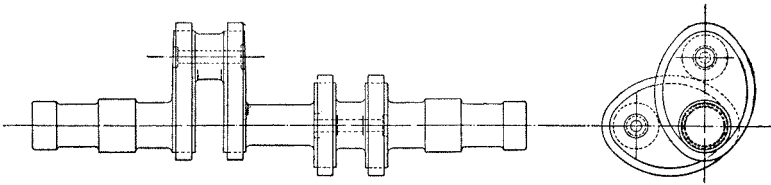
Fig. 11.—G.W.R. 4.4.0 and 2.6.0 classes.

Some of the early Metropolitan engines were fitted with cranks having fish-bellied webs, but hooped on outside webs only (Fig. 9). The crank shown in Fig. 10 has elliptical webs which are hooped. Fractures chiefly occur in journals close to the webs.

Fig. 12.

G.W.R, engines No. 3001-3080 are fitted with elliptically-webbed cranks (Fig. 12). These often break in the body, and sometimes fracture in the pins and inside journals.

Crank axles having circular webs (Fig. 13) are not common in this country. They are more costly to manufacture and are slightly heavier than other types. They are difficult to forge, but are easily machined.

Fig. 13.

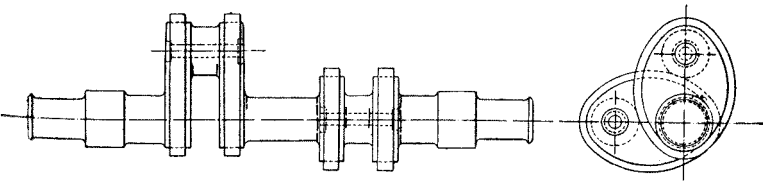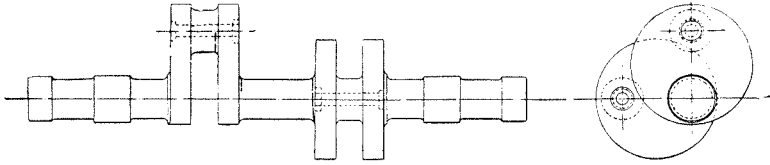BALANCED CRANKS.—Some engineers prefer to balance the crank by prolonging the webs, the idea being that, as all the revolving and part of the reciprocating masses are balanced in the axle and in the planes in which the disturbances are created, no rim weights need be provided in the wheels ; thus the axle is relieved of the destructive stresses caused by the balancing in the wheels. However, it is impossible to balance the axial and normal disturbing forces, because, if the balance weight is sufficient for the axial forces, it over-corrects the normal forces and introduces a new unbalanced force perpendicular to the line of stroke. This vertical force is very great, and acts dangerously in tending to throw the engine off the rails.

MANUFACTURE OF CRANK AXLES.— Crank axles should be made from good sound steel, and, after forging and annealing, should give results upon test bars, machined from the blocks removed from between the webs, without any further hammering or annealing, of from 28 to 35 tons per square inch tenacity, the elongation being 20 per cent. on $3''$; also, $1\frac{1}{4}''$ bending test, placed upon $6''$ supports, to obtain a right angle without any signs of failure.

The ingot should be cast heavier than the finished forging, so as to get sufficient material to form a sound crank, as the bottom portion of the ingot only should be used. The ingot should be heavy enough to allow one-third of the upper portion to be removed, owing to the tendency of very mild steel to pipe. The pipe should be allowed sufficient time to definitely form itself after the casting of the ingot, otherwise it will lead to trouble in forging.

A clink may sometimes occur in an ingot, and as this may not be external, it would, perhaps, be invisible even after machining. To overcome this it is advisable to charge them into the re-heaters, or soaking pits, before cooling. Care should be exercised in heating, as a repetition without mechanical work will change the nature of the fracture of any forging.

The ingot is drawn down to a slab (see Fig. 14), and brought to the hot saw and sawn for the webs. The gusset A is then cut out with a large cutter and the end roughly rounded. The portion between the webs is then removed by cutters, the staff changed, reheated, and the gusset B cut out and the end rounded. The hammer blocks are then changed for a smaller set, so that the middle can be rounded and then reheated for twisting (right hand web to lead in most cases). The second web is then placed between the anvil and tup, and the leading web has a large spanner attached, by which it is drawn up at
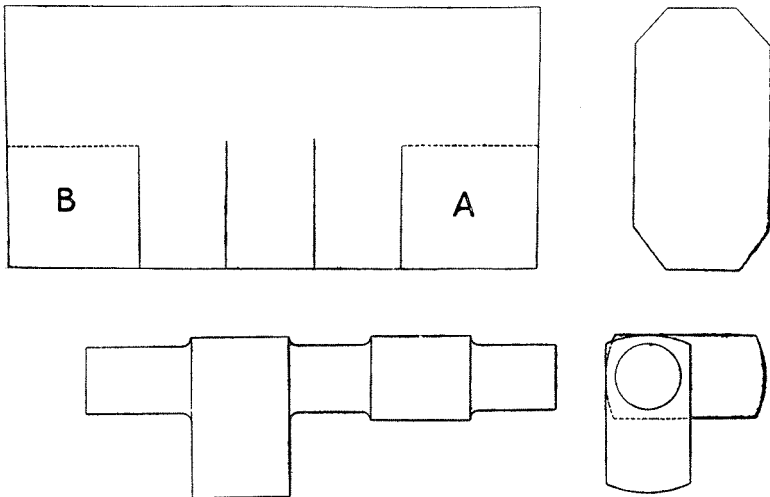

Fig. 14.

right angles. The middle is then hammered to its finished forge size, as are also the ends. The webs are next rounded under the hammer, top and bottom, and if found to be of slightly insufficient width, a fuller, consisting of a round bar, is stamped down the centre, which widens them out without affecting the thickness where it is required.

Considerable difference of opinion appears to exist as regards the hooping of cranks. Experiments have been made showing that when a crank web breaks nearly or quite straight across, the hoops are of the greatest value in holding the crank together ; but on the other hand when the fracture occurs in a slanting direction the hoop is of no use, as by its tightness it tends to force the broken parts away. The hooping of a crank practically lengthens it about 2ins., and there are many engines running in which hoops cannot be employed, in consequence of there being no available space between the crank and the underside of the boiler.
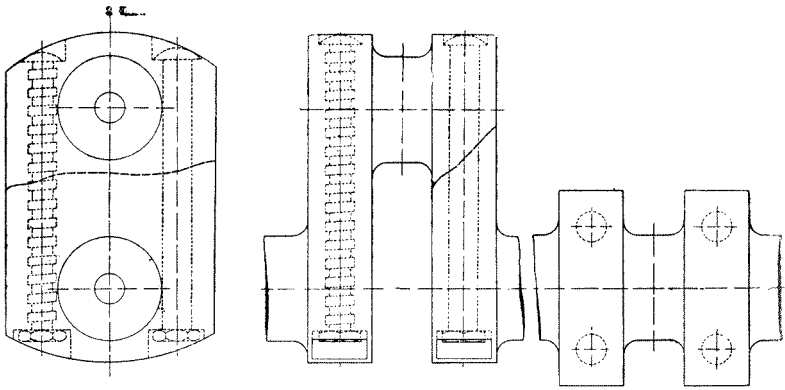

Fig. 14.

Fig. 15 illustrates a crank designed and patented by Mr. C. E. Stretton to overcome these difficulties. The crank is manufactured in the usual way, and the improvement for strengthening the webs consists in drilling two holes about 2″ diameter through the length of the webs. A bolt, pin, or screw is then passed through each hole. The bolt should be made of steel, having a tensile strength of 40 tons per square inch, and can be either screwed into the web or made a driving fit and forced in by hydraulic pressure and afterwards secured by a nut and split pin.

Iron was at one time chiefly used in the manufacture of cranks, probably as this material was more easily procurable, and also that railway companies manufactured their own cranks. In the manufacture of iron cranks it was found that after turning to finished sizes, seams were very apparent, this probably being due to the fact that the iron was not

properly clean or the heats made up of inferior material. Trains were not so heavy nor timed so quickly, and boiler pressure was not so high as at present ; so that a crank or axle was not subjected to such great strains as at the present day. Fractures occurred chiefly in the body, and occasionally in the pins. All flaws of small dimensions were kept under observation, and if after further mileage the flaw had extended greatly, the crank would be condemned. Later, in steel cranks, pins were inserted in the crank pins, not so much as a means of strength, but as a safeguard in case of the pin breaking through, as in this case it would hold the two webs together.

The introduction of trustworthy mild steel castings has replaced iron forgings to a very great extent. Cast-steel crank axles have been tried with success on a few railways. These have certain advantages, inasmuch as they may be guaranteed to be sound, homogeneous, and free from internal strains, and also possess a specified tenacity and ductility. They contrast favourably with built-up iron forgings and those from mild steel ingots. As the tensile strength of unforged steel castings is much greater than that of cast iron, they can be made much lighter than those of cast iron of equal strength ; but wherever steel castings are employed to replace forgings, the physical properties of those castings must be very carefully considered ; high tenacity being of less value than ductility. The utility of cranks depends to a greater extent upon their ductility than to a high-tenacity.

Although ordinary " carbon " steel has enormous advantages as regards strength compared with the wrought iron used for the details of engines years ago, it has its defects. It becomes weak and brittle after subjection to constant shock and loses its ability to resist sudden strains. By introducing a proportion of from 3 per cent. to 4 per cent. of nickel into the metal, a material possessing the maximum of toughness, tensile strength and durability is secured, which will successfully resist severe tests and repeated shocks. Although the cost will be, probably, increased, a considerable gain is expected from the reduced wear and tear and longer life and, also, a fracture which has been discovered does not extend as in the case of an ordinary steel crank. Nickel steel is much less liable to corrosion than ordinary steel or wrought iron, and the structure of ordinary steel as shewn when fractured is crystalline, whereas that of nickel is fibrous.

Built-up crank axles for locomotives (Figs. 16 & 17) are not altogether uncommon, and the method of building may be briefly described as
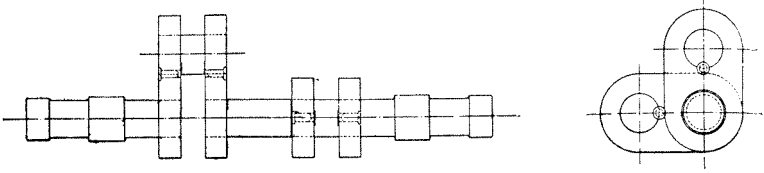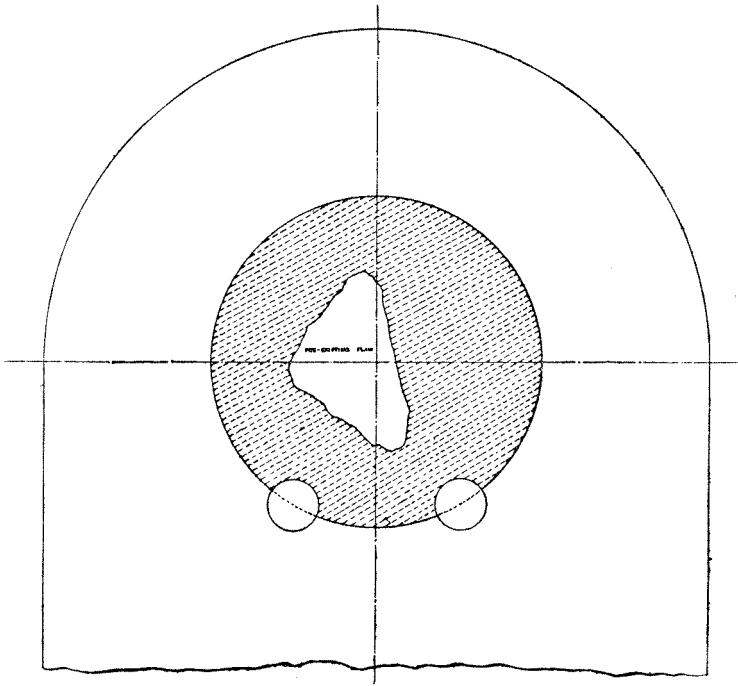

Fig. 16.

Fig. 17.

follows :—The webs are first planed and bored out to gauge to receive the body and crank pins, the body being turned slightly larger in diameter than the holes in the web. The webs are expanded, usually in a gas furnace, to receive the body and pins, and after fixing are partly cooled by compressed air and finally cooled in water. Holes, about $1\frac{1}{4}$ inches diameter, are drilled, half in the pin and half in the web. These are tapped and screws inserted to ensure the pins from revolving. When the whole crank is built up, the ends, body and journals are turned and keyways cut. The crank is then ready to be pressed into the wheels. An advantage possessed by built-up cranks is that they are capable of being repaired ; the initial cost is also less. They are heavier, stronger and more reliable than solid cranks and show a better mileage.

The question is frequently asked, " What is the cause of a crank axle breaking ? " and is one which deserves very careful attention. As the weight on the axle and steam pressure on the pistons are certainly not sufficient to account for the fracture, other causes must be looked for and examined. When an engine is running at a high speed there is a greater or less amount of oscillation ; this is kept in check by the flanges of the wheel, and great strain is put on the axle. It sometimes happens that the flanges of the wheels are pinched at points and crossings ; and it will be at once seen that this action must exert an enormous force upon the axle by the tendency to bend it upward in the body. This force is greatly increased with the size of the wheel, as the leverage or length of spokes is greater. Another source of trouble is caused by water in the cylinders, which sets up bending strain on the shaft. The application of sand while the engine is slipping, in the Author's opinion, is responsible for many loose crank pins and driving wheels. A frequent failure is that of being kept running too long. It has been considered that the maximum mileage of iron axles should not exceed 180,000 or 200,000, and of steel 150,000 or 200,000. Several steel cranks have attained wonderful mileage, 500,000 or more, and been in use for 20 years or so. It appears that if a steel crank is defective or flawed when new the failure takes place at an early period in its life, and that if it runs for 150,000 miles or more there is a great probability that it may afterwards run for a very great distance and last for several years.
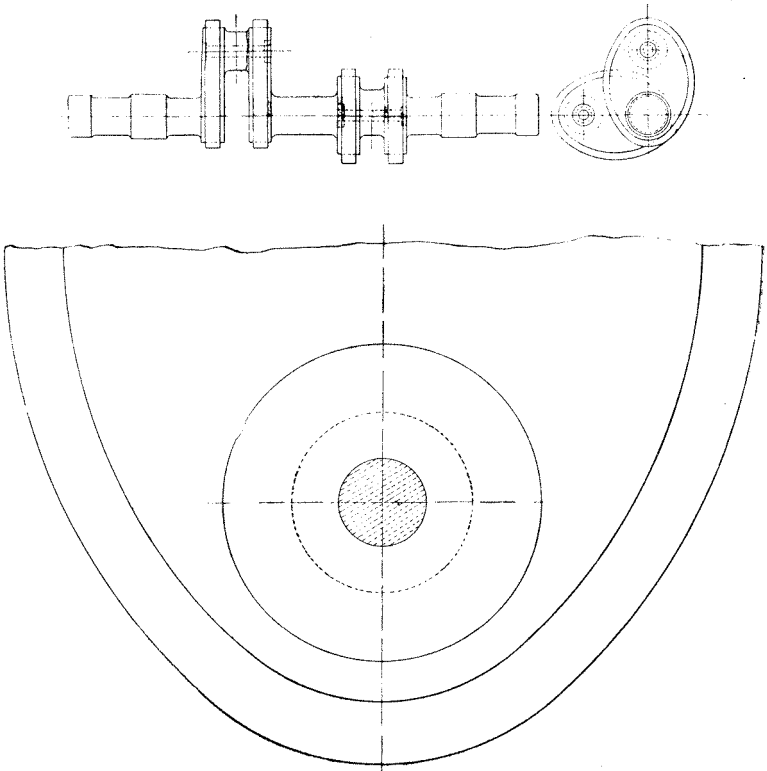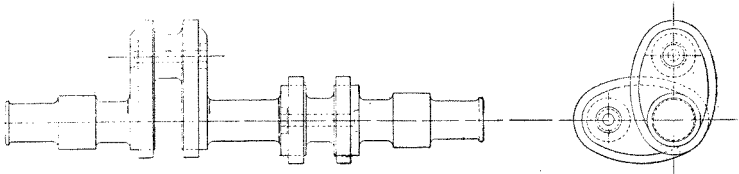
Fig. 18.

Fig. 19.
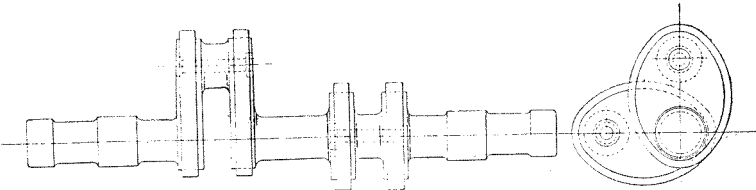
Fig. 20.— G.W.R. 4.4.0. and 2.6.0. class.
NOTE:— Thick lines indicate where fractures usually occur.

A crank shaft may be severely strained by its bearings being out of line ; by slackness in the brasses ; lack of lubrication on the pistons ; and its tensile strength may be diminished by long-continued excessive straining ; fatigue of metals and sudden application of the brake, especially when the tyres are worn ; and last, but not least, reversing the engine when running at a high speed.

Fig. 21.

Fig. 22.— G.W.R. 2.2.2. shewing fracture at keyway.

Figs. 18 to 22 will show where fractures usually occur in different types of crank axles.

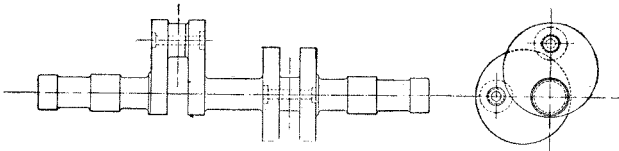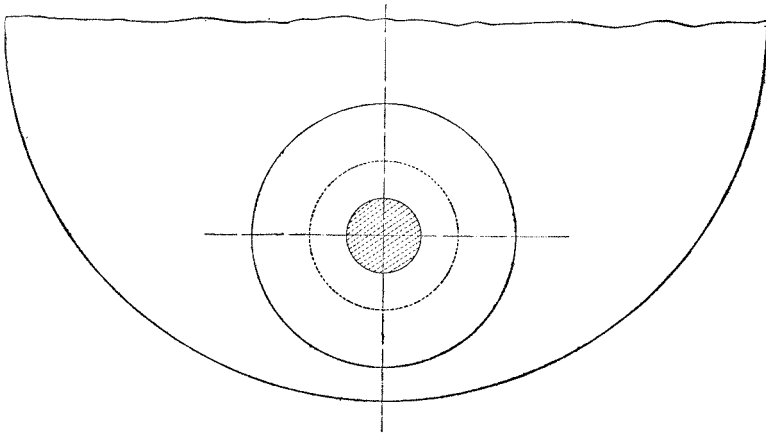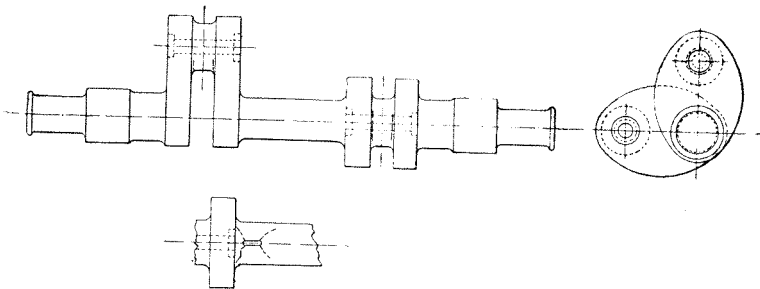In conclusion, the Author hopes that the paper has been of interest especially to those engaged on locomotive work. It is a subject which is not often discussed in engineering societies or amongst engineers, but nevertheless one of great importance. The Author here acknowledges his indebtedness to Messrs. J. F. Mclntosh, Loco. Superintendent, Caledonian Railway ; R. M. Deeley, Loco. Superintendent, Midland Railway ; and W. P. Reid, Loco. Superintendent, North British Railway, for their kindness and courtesy in supplying him with drawings of the various types of cranks in use on their respective railways.

DISCUSSION.

Mr. A. H. NASH, in opening the debate, said the subject before the meeting was one seldom discussed by engineers, but was of considerable importance, especially when it was remembered what a large number of crank axles failed a while ago on a certain class of engines where built-up cranks could not be used. He thought that in dealing with the causes of fracture, sufficient consideration was not given to the action of the brake, especially the vacuum brake. With the steam brake it took some time for the cylinder to warm up, and this removed the suddenness of the strain. Cranks, he thought, were losing somewhat of their importance now that outside cylinder engines were coming into greater use. He would like the Author to say what was meant by the term " pre-existing flaws," and to give, if possible, the shrinkage allowance in the manufacture of built-up cranks.

The Author, replying, said that the term " pre-existing flaw " was used to describe a flaw existing from the building of the crank, as grain flaws due to bad metal or bad workmanship. The shrinkage allowance on built-up cranks was usually about $\frac{1}{64}$ in.

Mr. G. A. BOWERS thought cast steel cranks inferior to the ordinary bloom rolled crank, being more liable to porosity ; many steel castings of various forms had been found to be honeycombed within when broken.

Mr. C. C. HENRY asked the Author if any trouble was experienced with built-up cranks in keeping the throws in their proper relative

positions ; he thought they were very liable to get twisted on the shaft. He had seen an instance of a pin coming out while running.

Mr. S. E. Tyrwhitt, referring to the question of built-up cranks twisting, said he thought Mr. Haggard could possibly give some information on the subject.

Mr W. J. Haggard said the instance of a securing pin coming out of a built-up crank while running, referred to by Mr. Henry, was quite an isolated case, and was not due to ordinary circumstances, but probably to some improper treatment.   Rectangular keys had been tried, but were not a success in that they were liable to slide back in cases of severe shock.   With regard to the twisting of webs on the shafts of built-up cranks, his experience of such cases had been very limited, and only happened, he thought, where the axles had been subjected to a severe strain such as would be caused by sudden reversing by steam reversing gear.   He quoted one case in which a test was made by dropping a tup on the web that had moved, but failed to get it back to its original position, moving it only very slightly indeed. He mentioned that the shrinkage allowance asked for by the Chairman was, on the L. & N.W.R., $\frac{1}{64}$ in.; G.W.R, was slightly less, the idea being to avoid bursting of the webs.   Speaking of crank axle fractures generally, he found the double-framed engines far more destructive than single-framed ; this he thought due probably to the increased strain consequent upon the revolution of such large masses of metal as the outside cranks, rods, etc., at a greater distance from the inside crank throws than is the case with single-framed engines.   He further thought that the removal of the flange on the driving tyre — a reversion to old practice — might result in reducing the number of fractured crank axles. The progress of a fracture was, he considered, considerably hastened once the fracture (ever so small) had commenced, by the oil and dirt getting into it, assisted by the vibration.   At the present time the strains put upon a crank were much greater than formerly.   He strongly condemned, as injurious to the life of a crank axle, the practice of reducing the diameter of the shaft at any point throughout its length. A fracture usually started with a very fine hair line, which could only be detected by a trained inspector.   Mr. Haggard, referring to straight axles, said the $\frac{1}{4}$in. collar, which was usual on straight axles, was in his opinion responsible for 50 per cent, of the fractures found in them.   The collar set up a vibration in running.

Mr. L. A. BREWER asked if there were any restrictions on English railways as to the weight carried on driving wheels. In Germany it was limited to 16 tons, in Belgium 18, in France 22, on the N.E.R. 22, and he believed on the G.W.R, it was 20 tons.

The Author replied that in England it was usually 20 tons.

Mr. NASH, referring to Mr. Haggard's remarks on double-framed engines being more destructive on crank axles than single-framed, said he thought outside bearings would save them, as they would have the advantage of additional support in the bearings.

Mr. HAGGARD supplemented his previous remarks on the subject, saying that a double-framed engine had three or four broken crank axles to one on a single-framed engine. He considered the best form of web (although difficult to forge) was the taper web, as employed in the early Metropolitan engines. With these engines, despite the bad roads and the severe strains of frequent stopping, etc., a crank axle failure was a *rara avis ;* this was probably due to the greater flexibility of the web. Some of these axles put in in 1875 or 1876 were still running with excellent mileages.

Mr. TYRWHITT thought the reason double-framed engines were so heavy on crank axles might be traced to their rigidity.

Mr. HAGGARD supported the statement that the brake power was responsible for much of the damage by quoting cases of the spokes being broken (near the boss, generally) by the sudden application of efficient brakes. This tendency was greater the larger the diameter of the wheel. He had known instances where only one spoke remained sound out of 24.

Mr. BREWER, referring to the Author's contention that an increase in the diameter of the axle reduced its flexibility, pointed out that American railway companies usually adopted larger diameters than English companies in proportion to the load, and he believed they had a higher percentage of phosphorus and manganese.

Mr. HOLCROFT, speaking on the subject of double *versus* single-framed engines, suggested that the double-framed broke more cranks, because, carrying heavier weights on the outside journals, when the engine struck a crossing the outside weight would accentuate the stress. He thought a central bearing might be an improvement. Many of the L. & N.W.R. engines were fitted with Joy's valve gear and, therefore,

had the three bearings. He questioned if the centrifugal force set up by the crank webs being at right angles had been sufficiently considered.

Mr. HAGGARD considered the longevity of cranks experienced on other railways was contributed to by their adoption of larger bearings. Iron crank axles had been referred to as being superior to steel. Many considered this to be so because in looking back it was seen that better results were obtained than steel now gives, but it should not be over-looked that the strains were not so great years ago as at present. The superiority of iron over steel then appeared to have been only sup-position. An experiment to test this was tried some few years ago, a crank axle being made from Lowmoor iron tyres. After five months running it was a wreck.

The Author, replying to Mr. Brewer's remark upon the larger diameters of the American axles, said the Americans used a higher percentage of manganese.

Mr. BREWER described a peculiar form of built-up crank axle in use on Belgian State railways, having a bent shaft between the webs. It is called the Z axle and has a square body.

Mr. NASH said this form of axle was called the Z axle and was used on the four-crank one-axle system of Von Borries. It was claimed for it that the stress was more evenly divided between the two crank pins which the body connected by a rigid square bar.

Mr. HAGGARD thought the axle was weakened and great strain at the same time thrown upon it by keying the eccentric sheave to the body. On the L. & N.W. and L. & S.W. Railways he believed some eccentric sheaves were secured to the webs. The greater strength of the web over the body being thus taken advantage of.