Vertical Boiler Locomotives

By R. A. S. ABBOTT*

No. III—(*Continued from page 765, June 3rd*)

The study of the history of the industrial locomotive is a fascinating subject, quite outside the scope of ordinary railway and locomotive literature, and one which offers a wide field for research. For many years the writer has made the industrial and light locomotives with vertical boilers his special interest, and as no previous history of this type of locomotive has ever been published it is hoped that this excursion into a little explored by-way of locomotive engineering will prove welcome to both the engineer and historian.

Merryweather Tramcar Engine

THE early experimenters with steam tramcars evidently soon came to the conclusion that an independent locomotive would be much more satisfactory in many ways to an engine combined with the tramcar, and so in 1875 we find that Messrs. Merryweather and Sons, of Greenwich, constructed a small experimental locomotive. The vertical boiler was fitted with "Field" tubes and was similar in construction to those fitted to the firm's fire-engines since 1861. Two cylinders, 6in diameter by 9in stroke, were placed horizontally on the centre lines of the axles so that the vertical motion of the bearing springs, of the coil type, should not affect the action of the valve gear. A sheet iron box protected the motion from the dust.

A water tank was fitted at one end and a coke bunker at the other, leaving a clear gangway on each side of the locomotive. The exhaust steam was superheated in a box arranged at the bottom of the chimney uptake, being conducted thence by pipes, passing through the ashpan and inside the firebox. This arrangement was found to heat the steam sufficiently to render it invisible. The iron dish surrounding the uptake was placed there to catch the dislodged scale and prevent it falling into the "Field" tubes. The length of the cab was only 6ft 6in, and the total weight of the locomotive with fuel and water was under 4 tons.

A second locomotive appeared in 1876, and this also had a Merryweather and Field boiler, with superheating apparatus and scale catcher as in the earlier one. A vertical steam cylinder was placed on either side of the vertical boiler, driving through suitable gearing to one axle, the wheels being coupled by rods. The total weight was only 5 tons, and it is understood that in order to obtain proper adhesion when ascending steep inclines, part of the tramcar weight could be thrown on to the locomotive frame.

The locomotive had the appearance of being merely the power bogie of a combined car, but as the weight was only taken on hills it was presumably a separate machine. These two locomotives were both sent to Paris. The issue of *Engineering* for March 9, 1883, illustrated and described these two locomotives.

Many years later, about 1907, a vertical boiler inspection locomotive was built by Merryweathers for the Buenos Ayres and Pacific Railway, and this machine was fully described and illustrated in *The Locomotive* for 1907, page 133.

Locomotives from Caernarvon

Although primarily intended for the narrow gauge lines in the local slate and granite quarries of Caernarvonshire and Merioneth, the small vertical boiler locomotives constructed by Messrs. de Winton and Co., Union Works, Caernarvon, were afterwards supplied for use further afield and for gauges up to 4ft 8½in. Exactly how many were built is not known, probably about fifty, but thirty-seven two-cylinder and two single-cylinder examples have been traced, all built between 1875 and 1897. Of the single-cylinder design little is known beyond the fact that they had direct drive and double-flanged wheels, and being very small could be used closed up to the working face in quarries for supplying steam to rock drills. Two were owned by the Glyn-Rhonwy Slate Quarries at Llanberis.

The 1ft 11½in gauge locomotives (Fig. 15) of the two-cylinder type, had a solid plate frame outside the disc wheels, and being without springs the bearings were fixed directly in these frames. At the front end was the small water tank, at the other end the coal bunker, with the boiler mounted very low in the centre between the axles. The fire was fed through a trapdoor in the footplate and the coal slid down a chute on to the grate. These boilers were 2ft 7½in diameter and 4ft 10½in high, made of Low Moor iron and fitted with seventy-six tubes of 1¼in diameter; grate area, 3·4 square feet. The Ramsbottom safety valve, fitted on a bracket on the left-hand side, blew off at 120 lb per square inch.

On most locomotives the chimney was in the top centre of the boiler above the smokebox, but as condensed steam and rainwater was found to run down the short chimney and cause the top tube plate to corrode, the design was altered in the later examples to provide for a smokebox placed staggered fashion in advance of the boiler top. The two vertical cylinders were fixed to the boiler front by two steel plates, one on either side of, and partially embracing, the boiler. The drive was direct on to the front axle without gearing, the connecting-rod big-ends being of the marine type.

The "Victoria," built in 1897, differed in being fitted with a free-standing launch type engine and driving the axle through an intermediate shaft. This can be seen in Fig. 16, which also shows the offset type of smokebox. It is thought that this was the last de Winton locomotive built. The valve gear was originally Joy's, but later Stephenson's gear was adopted in conjunction with a special form of slide valve designed by Charles Cousins, chief draughtsman during the 1880s; the reversing quadrant was on the right-hand side of the footplate. Other dimensions were: wheels 1ft 8in diameter; wheel base—this varied from 4ft to 4ft 4in length over frames 8ft 6in; overall width, 3ft 6in; height to top of chimney, 6ft 9in. This class was used at the Penrhyn Quarries, Bethesda; Pen-yr-Orsedd Quarry, Nantlle; Cilgwyn Quarry, Carmel; Alexandra Quarry, Rhosgatfan; Oakley Quarries, Blaenau Festiniog; Dorothea Quarry, Tabysarn; and Greave's Llechwedd Quarry, Blaenau Festiniog.

A drastic variation from the standard design was made in the case of the "Arthur," built for the Pen-yr-Orsedd Quarry in 1890 and illustrated here in Fig. 17. In this design the water tank was placed close to the boiler and the engine at the front end of the frame with the drive from the crankshaft to the front axle by outside cranks and coupling rods. Whether this particular locomotive was the only one produced to this pattern is not known.

The 3ft gauge series, Fig. 18, were slightly larger and had inside frames. The dimensions were: boiler, 2ft 10in diameter and 5ft 3½in high; grate, 2ft 1¼in diameter;

* Member, Newcomen Society; Member, Industrial Locomotive Society.

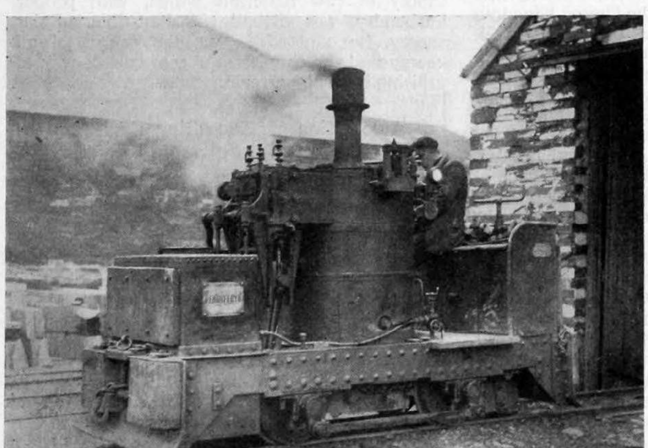

Fig. 15—de Winton locomotive "Pendyffryn" for 1ft 11½in gauge, Pen-yr-Orsedd quarry, Nantlle

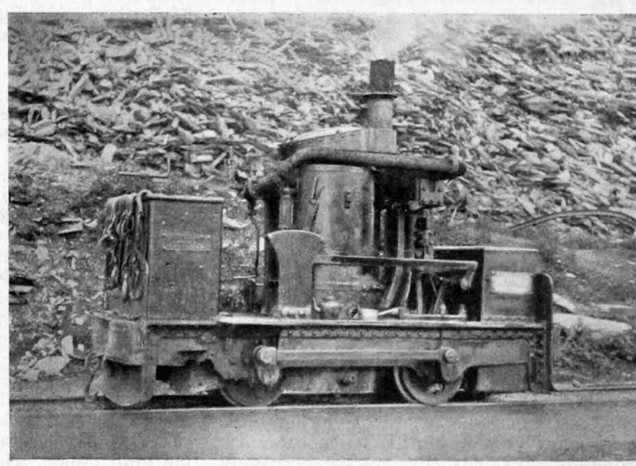

Fig. 16—de Winton locomotive "Victoria," built in 1897, with geared drive, Pen-yr-Orsedd quarry, Nantlle

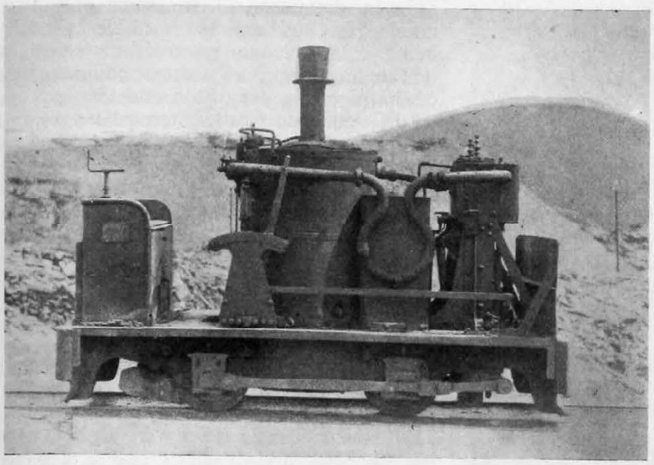

Fig. 17—de Winton locomotive "Arthur," built in 1890, with rod drive, Pen-yr-Orsedd quarry, Nantlle

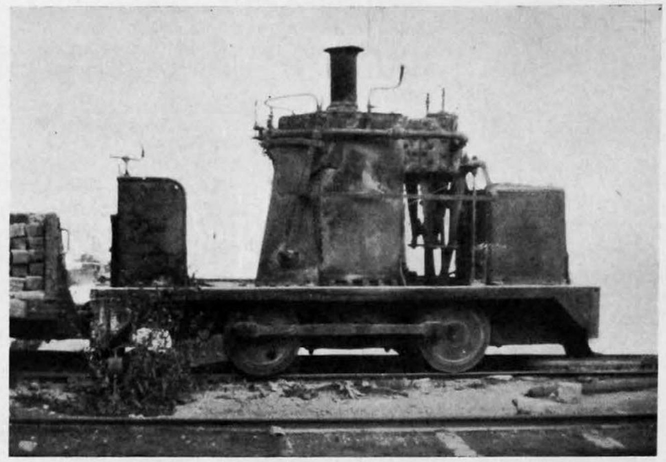

Fig. 18—de Winton locomotive "Watkin" for 3ft gauge, built in 1893 for Darbishires, Ltd., Graiglwyd quarry, Penmaenmawr

pressure, 120 lb per square inch; wheels, 1ft 8in diameter; wheel base, 4ft 5in; length over frames, 11ft 7in; overall width, 4ft 3in; the price of one of these locomotives in 1894 was £430. The illustration, Fig. 19, is an underside view of one of the 3ft gauge locomotives, and is interesting in that it shows how the frames were formed with an outward bulge to accommodate the firebox; this form of construction was also used on locomotives built for the narrower 1ft 11½in gauge, but was not universally employed. The view also shows the coal chute from the footplate down to the firegrate, and it will be seen that the axle bearings were simple plummer blocks attached direct to the frames.

Locomotives of this gauge went to Messrs. Darbishire's Graiglwyd Quarries, Penmaenmawr, and to Brundrit and Co., Penmaenmawr. The original cylinder dimensions of all these locomotives are doubtful, as most of the survivors have been rebored at least once, but recent measurements show that cylinders of 6¼in diameter by 10in stroke and 6¼in diameter by 12in stroke are to be found on the 1ft 11½in gauge, and 5¾in diameter by 10in stroke and 6¾in diameter by 12in stroke on the 3ft gauge. The weights are likewise uncertain, as some locomotives have had thick slabs of steel plate laid flat on the top of the frames on either side of the boiler to increase the adhesion. Two of the Penmaenmawr locomotives that have been so treated weigh 5 tons 15 cwt, but otherwise the average weight on both the narrow gauge engines appears to have been 4½ tons empty and 5 tons when in working order.

The only example of a standard gauge de Winton locomotive known to the writer is illustrated in *The Locomotive* for 1905, page 138. It is of interest to record that although the last de Winton locomotive was built in 1897, the firm quoted for the supply and delivery of one to the phosphate company operating on Christmas Island about 1900.

Balmforth Design

Messrs. Balmforth Bros., Peelings Foundry, Rodley, near Leeds, were manufacturers of locomotive steam cranes, contractors' locomotives, hoists, and all kinds of lifting machinery. Their contractors' locomotives were of a very unusual design, combining vertical boiler, outside sloping cylinders and outside frames, the whole being carried on four half-elliptic springs mounted above the frames, Fig 21. Just how many were built cannot now be ascertained, but fortunately two such locomotives are still owned by Mr. W. Hunter, proprietor of the extensive gravel pits at the south end of Walney Island, and through the kindness of Mr. M. Carter, of Barrow, it has been possible to record a few dimensions. The wheels are 1ft 10in diameter; cylinders, 8in diameter by 14in stroke; and the gauge is 3ft.

The curious valve gear should be noted; the Stephenson link motion actuates, through a rocking shaft, the long rod seen on the outside of the frames extending from the front of the locomotive right to the valve chest. The connecting-rods are of round section with marine type big ends, Fig. 20. When new, the boilers had cross tubes and worked at 60 lb per square inch. The present-day weight is 7 tons and the average load hauled with ease is 60 tons.

As to the period during which Messrs. Balmforth manufactured this class of locomotive, it is known that one of these Walney Island locomotives was purchased secondhand in 1896, and was said at that time to have been twenty years old, so the date of building would be *circa* 1876. Another locomotive of this make worked at Newby Brickworks, Annan, bearing the name "Ivanhoe." It started work prior to 1890 and was scrapped in 1910. A small engraving of a Balmforth locomotive will be found in the firm's advertisements which appeared in *Engineering* during the 1880s, where it is also stated that all boilers then being made were fitted with Fox patented corrugated steel fireboxes.

Kitson Engines

Three experimental locomotives with vertical boilers were built in 1878 at the famous Airedale Foundry of Kitson and Co. Ltd., Leeds, and although not supplied to any specific order, two of them eventually

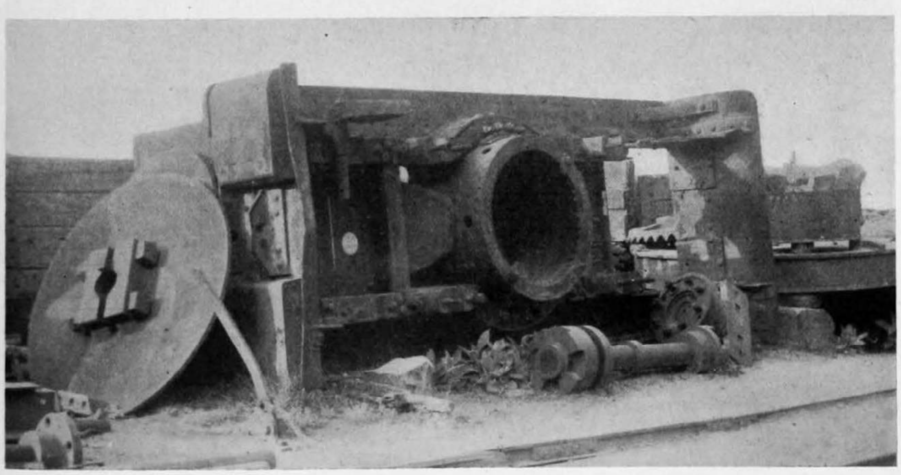

Fig. 19—de Winton locomotive frame showing outward bulge to accommodate the firebox

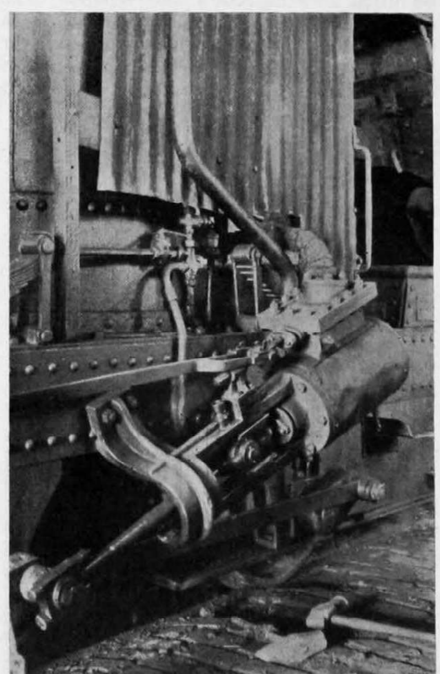

Fig. 20—Balmforth locomotive showing marine type big ends

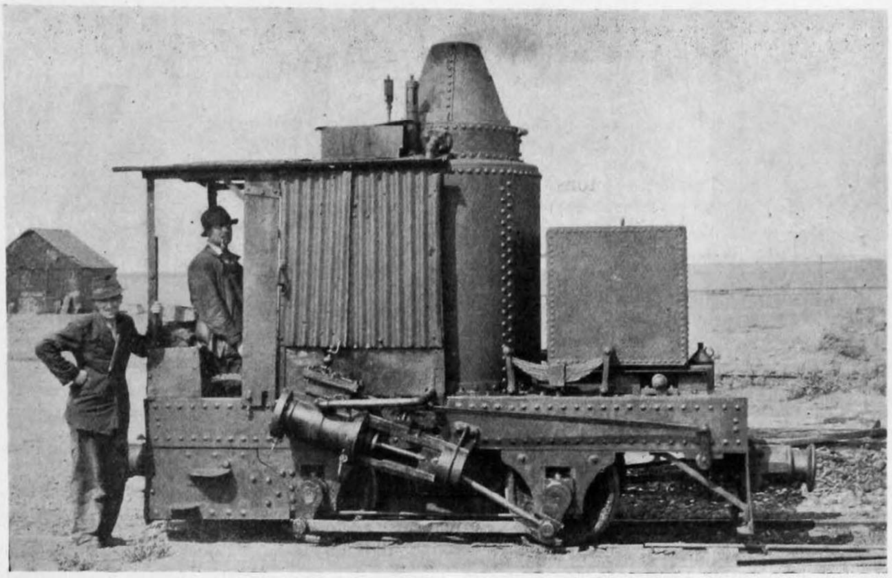

Fig. 21—Locomotive by Balmforth Bros., of Rodley, at the gravel pits on Walney Island

worked on the tramways at Hamburg and Rouen, while the third was purchased by the Great Eastern Railway Company for use on its Millwall Extension line. This latter locomotive was illustrated on page 262 of *The Locomotive* for 1910 and was there described as having two cylinders placed vertically and driving a shaft placed transversely between the two axles, from whence the drive was taken to the running wheels by coupling rods. These cylinders were on either side of the vertical boiler and were visible through the side windows. The four coupled wheels were 2ft diameter on a wheel base of 4ft 6in. The boiler, fitted with 130 cross water tubes, provided a heating surface of 80 square feet, while the grate area was 3·17 square feet. It was designed for a working pressure of 150 lb per square inch and had a diameter of 2ft 5in with an extreme height of 5ft 6in, while the outer shell was made in two parts, so that the top part could be lifted for inspection and repairs. The overall height to top of chimney was 12ft 8½in and the total length of the locomotive over body was 10ft 8in, with an extreme width of 7ft 1¾in. The multitubular air-cooled condenser in the roof gave a cooling surface of 452 square feet.

These three locomotives may not have been exactly alike in design, for the late Dr. Whitcomb in his *History of the Steam Tram* says that the cylinders were placed high up outside the frames and inclined slightly from the horizontal, and that Kitson valve gear was fitted. Due to the closing down of the Airedale Foundry as a locomotive works, and the destruction and loss of most of the records, there now seems little chance of this doubtful point being cleared up.

Greenwood and Batley

In 1878, Greenwood and Batley, Ltd., Albion Works, Leeds, constructed for Loftus Perkins a somewhat larger vertical boiler tramway locomotive, Fig. 22, of a similar design to that sent to Brussels by the Yorkshire Engine Company, in 1874. The engine, however, was arranged for triple expansion, the high-pressure cylinder having a diameter of 3⅛in, the intermediate cylinder a diameter of 5½in, while the low-pressure cylinder was 7½in in diameter. There were only two cranks, the high and intermediate cylinders being arranged in tandem with the two pistons on the same rod. The steam acted on the top of the high-pressure piston and then passed to the underside of the intermediate piston, finally passing to the low-pressure cylinder, which was double-acting; the common stroke was 9in. The gear ratio between crankshaft and countershaft was 4 to 1, with the final drive by coupling rods to the 2ft diameter wheels set on a wheel base of 4ft 3in, the gauge being 4ft 8½in.

The Perkins boiler provided a heating surface of 90 square feet, with a grate area of 3 square feet, and carried a working pressure of 500 lb per square inch. The boiler feed water was supplied by one steam donkey pump and one mechanically driven pump. The brass condenser tubes were 6ft high and ½in diameter and together had a cooling surface of 1500 square feet.

This locomotive was 10ft long, 7ft wide and 9ft 8in high excluding chimney; it weighed in working order 6 tons. It was tried on the Leeds Tramways but does not seem to have done any useful work.

Ransomes and Rapier

Ransomes and Rapier, Ltd,, Waterside Works, Ipswich, was established in 1868 for the manufacture of general railway plant, such as chairs, rails and points, but a few years later the firm commenced building various kinds of narrow-gauge locomotives, among which was a series of vertical boiler inspection locomotives, the prototype of which had originally been designed and built for export to one of the Colonies. The illustration, Fig 23, is from Ransomes and Rapier's official photograph No. 90 and it is understood that a woodcut of this photograph appeared in a catalogue for the year 1880, which gives some indication of the date when these locomotives were being built. As very little appears to be known about these locomotives, and the writer has as yet found no other contemporary account, it will be convenient here to quote from the makers' catalogue: " Steam Carriage suitable for rails of 18–20 lbs. per yard. . . . This engine has since done exceedingly good service, both as an auxiliary on ordinary railways and as principal Engine

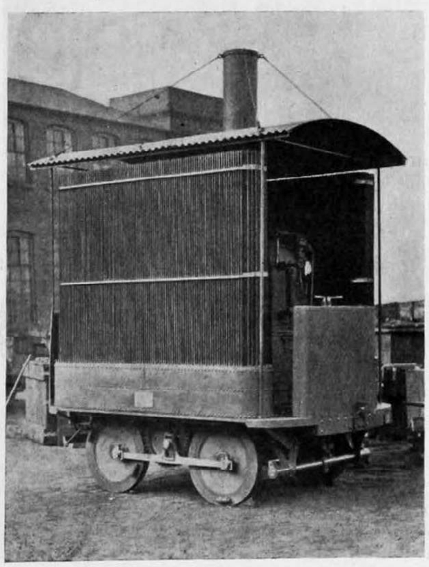

Fig. 22—Loftus Perkins high-pressure tram locomotive by Greenwood and Batley, Ltd., 1878

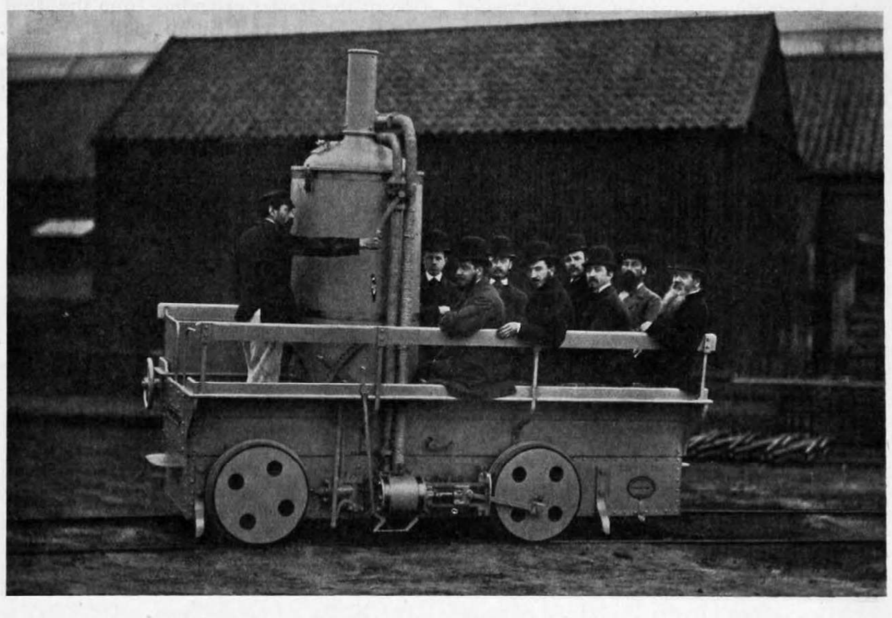

Fig. 23—Ransomes and Rapier's inspection locomotive, circa 1878

on light railways. It is practically a combination of Engine, Tender, Brake and Carriage, all in one; and it is the least expensive contrivance for travelling 20 miles an hour which has yet been produced. For economy of space, the boiler is made of the vertical type, with grate surface and heating surface so ample as to enable a good supply of steam to be easily maintained, even when burning wood or refuse fuel. The Engine has two cylinders, and is fitted with reversing gear, and all other fittings usual in the best locomotive work. It can be made of any gauge from 2 feet to 5 feet 6 inches, according to the gauge of the railways in the locality. If there are no railways, the best gauge will be 3 feet or 3 feet 6 inches. We build these Engines on stock, and can finish them at short notice to any of the following gauges, viz., 3 feet, metre, or 3 feet 6 inches. The example here given has the following leading features and dimensions :—

" Maintained speed 20 miles per hour, with light loads.

" Maximum train load at 8 MPH. on level, 80 tons.

" " " " 5 MPH. on 1 in 100, 40 tons.

" " " " 3 MPH. on 1 in 35, 20 tons.

" Supply of coal and water for 30 miles.

" Weight in working order 6 tons.

" Cylinders 7 inches diameter by 10 inches stroke, wheels 1 foot 8 inches diameter.

" Length overall 11 feet.

" Room for 6 or 8 passengers.

" Fitted with locker to contain mails and parcels.

" Price of the machine, if fitted with roof, £480, price for enclosing with glass windows £40."

These locomotives were spring mounted, and all appear to have had disc wheels, but not always of the same pattern, some being solid, while others had the circular holes as shown in the illustration.

(To be continued)

Silicon Alloy Junction Diodes for Power Supply Application

By J. SHIELDS, B.Sc.*

The development of convenient methods of growing large single crystals of germanium and silicon has led in recent years to the production of many low current semi-conducting devices and their application in circuit construction. At present germanium is being used to a greater extent than silicon, but the ability of silicon devices to operate satisfactorily at temperatures as high as 200 deg. Cent. suggests that, in future, silicon will replace germanium in many applications. Recently, widespread interest has been shown in the application of germanium to the field of power rectification : this article summarises work carried out in the B.T.H. research laboratory in making experimental silicon rectifiers and in examining their characteristics.

SILICON in its pure state is a poor conductor, but disturbances in the crystal lattice, caused, for example, by the presence of small amounts of impurities to the extent of less than 1 part in 10^6, can cause considerable changes in its conductivity. Two main classes of impurities are recognised, " donors " and " acceptors," the mechanism of conduction depending on which class of impurities is present in excess. " Donor " impurities result in a surplus of free electrons which conduct current by the passage of negative charges through the crystal, a crystal with excess electrons being called " *n*-type." Phosphorus, arsenic and antimony act as donor impurities in silicon. " Acceptor " impurities result in a deficiency of electrons creating " positive holes " which are mobile and can conduct current through the crystal.[1] A crystal with a deficit of electrons is called " *p*-type." Aluminium, boron, gallium and indium act as acceptor impurities in silicon.

A change from *p*-type to *n*-type material inside a crystal results in a junction which exhibits rectifying properties. This *p-n* junction has a low resistance to current flow from the *p* to *n* region, but a very high resistance to current flowing from the *n* to *p* region.

Two kinds of *p-n* junction have been produced :—

(*a*) Junctions prepared by careful control of conditions during the growth of the single crystal (commonly called " grown junctions ").

(*b*) Junctions prepared by the diffusion or alloying of impurities into the crystal after growth (commonly called " diffusion junctions " or "alloy junctions ").

In the present investigations the junctions considered are of the " alloy " type.

Materials and Diode Construction

Junction devices are prepared from wafers from single crystal silicon cut perpendicular to the direction of growth. These single crystals have been grown in the laboratory by the Czochralski technique—a single crystal is shown in Fig. 2. For the purpose of the present investigation wafers have been taken from a selection of *n*-type single crystals of electrical resistivities from 0·7 to 10 ohm-centimetre.

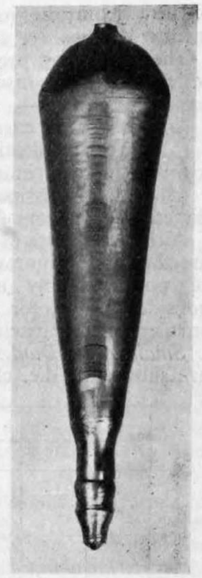

Fig. 2—A single crystal of silicon grown by the Czochralski method

The *p-n* junction diodes are prepared by alloying, at high temperatures, donor and acceptor impurities to opposite faces of a silicon wafer. In this instance aluminium is used as the acceptor impurity and antimony as the donor. It has been suggested by Herold[2] that the junctions should be grown by deposition from the solid solution of silicon and the impurity during the cooling cycle, the junctions being situated between the unmelted silicon and the deposited solid solution. A schematic representation of an alloy diode is shown in Fig. 3. After assembly the diode is carefully cleaned and then insulated from atmospheric contamination.

Electrical Properties of Junction Diodes

Fig. 1 gives the d.c. characteristics of several kinds of silicon alloy junction diodes constructed in the B.T.H. research laboratory. The diodes have ranges of forward currents from milliamperes to tens of amperes.

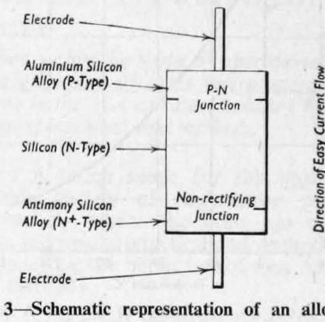

Fig. 3—Schematic representation of an alloy diode

Most rectifying diodes have a particular field of application governed mainly by their power handling capacity in the forward direction of current flow, although diodes of type *B*, Fig. 1, are of interest because of their unusual reverse characteristics. This power handling capacity is dependent mainly on the area of the rectifying junction, the ambient temperature, the efficiency of removal

* B.T.H. Research Laboratory

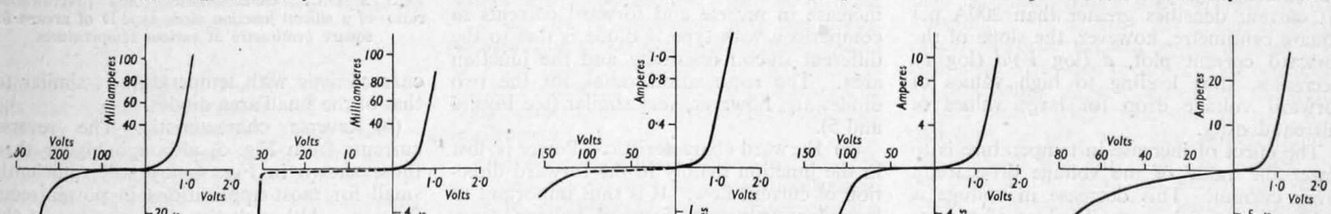

Fig. 1—Characteristics of various silicon alloy junction diodes