(Paper No. 3168.)

“The Mechanical Equipment of the Snowdon Mountain Railway.”

By GOWRIE COLQUHOUN AITCHISON, Assoc. M. Inst. C.E.

THE Snowdon Mountain Railway starts from Llanberis at a point some 350 feet above the sea-level, and ascends with varying gradients, ranging between 1 in 20 and 1 in 5·5, until it reaches the upper terminus, which lies about 50 feet below the actual summit of the mountain, which is 3,560 feet high. The total rise of the railway from terminus to terminus is 3,140 feet, and the length is 4 miles 54 chains, the average gradient being 1 in 7·83. The system adopted is that known as the “Abt,” and rack is used for the whole length of the line, and on all sidings and turnouts, as well as in the engine- and carriage-sheds. The line is single, but three passing places or turnouts are provided at practically equal distances, as well as a double track at each terminal station of sufficient length to hold a full train. The sharpest curve is of 4 chains radius.

Permanent Way.—The gauge is 2 feet 7½ inches, and the permanent way is of steel throughout. The bearing rails are rolled to the Indian State Railway section; they are flanged, and weigh 41½ lbs. per yard. The sleepers are of rolled steel, 6 feet long by ⅜ inch thick on the crown, gradually tapering off in thickness at the sides; their ends are doubled down, and they weigh 67 lbs. each. The bearing rails are fastened to these sleepers by clips, which are fixed to the sleeper by hook bolts; each clip has a projection on its under side, which, together with the hook bolt, fits into an oblong hole through the crown of the sleeper.

The gauge is widened as required on the curves by this projection on the under side of the clip being varied in size. Sleepers are spaced regularly 2 feet 11½ inches apart. The rack, which is double, is of mild rolled steel, and is carried down the centre of the line on rolled steel chairs weighing 12 lbs. each, machined on

the faces against which the rack-bars fit. These chairs are connected to the sleeper by two $\frac{3}{4}$ -inch steel bolts, the square heads of which are rigidly held on the under side of the sleeper by a channelled iron plate. Rack-bars of varying strength are used, according to the steepness of the gradient: on gradients below 1 in 9, the thickness of rack-bar is 20 millimetres¹; on gradients of 1 in 9 and over, the thickness of rack-bar is 25 millimetres. The rack-bars are 5 feet $10\frac{7}{8}$ inches long, and are so laid that the tooth of the bar on one side of the chair comes opposite the space of the bar on the other side. The weight per rack-bar of 25 millimetres in thickness is 67 lbs., and per rack-bar of 20 millimetres in thickness $53\frac{1}{2}$ lbs. All rack-bars are $4\frac{5}{16}$ inches in depth. Two $\frac{3}{4}$ -inch fish-bolts fasten the rack-bars to each chair.

The following are the dimensions of the teeth:—

	Millimetres.
Depth of tooth	50
Centre to centre of teeth	120
Length at pitch line	60

There is now on all gradients (but dropped off at the crossings) what may be termed a "safety angle-bar," an arrangement designed with a view to supplying an additional safeguard against the possibility of the cogs on the engine pinions mounting and thus losing or reducing their engagement with the teeth of the rack. This angle-bar is of rolled steel, and attached to each side of the rack-bars by the same bolts which hold the rack-bars to the chairs. It is laid in various lengths to suit both vertical and horizontal curves, and dowel pins are inserted at the ends to secure correct alignment at the joints. In consequence of the variation in the thickness of the rack-bars (as before described), a 5-millimetre washer has to be introduced between the 20-millimetre rack-bar and the angle-bar, in order that the latter should always be the same distance from the centre throughout. Two grippers are attached to each engine, and one, or in some cases two, to each carriage. These are so adjusted that they never come in contact with the angle-bar unless there be a tendency to mount, when the gripper will at once come into action by catching under the flanges of the angle-bar.

All rails, rack-bars, and angle-bars are fish-plated. The bolt-holes at the lower end of the bearing rails are round, but those at the upper end are oval, so that expansion takes place up hill.

¹ The English equivalents of the metric values will be found on p. 272.

Each rack-bar has four bolt-holes, the two in the centre being round, while those at each end are oval, expansion being thus allowed for from the centre. To prevent creeping, iron stays or uprights are set at intervals in solid concrete blocks, and the lower side of a joint sleeper is allowed to rest against them. The spacing of these anchors depends on the steepness of the gradient. On the 1 in 6 gradients they are about 60 yards apart.

The crossings adopted on the Snowdon Railway are of rather a complicated character, as the rack is carried right through, thus making a continuous track for the engine pinions. The switches are 12 feet in length, the radius of curve being 151 feet $3\frac{3}{4}$ inches, the rate of crossing about 1 in $4\frac{1}{2}$, and the angle 13° . The rods and levers which work the points are connected with and work hinged portions of the rack, which are thus brought into correct position at the same time as the points are thrown over. This provides a continuous rack for the passing of the engine, and also clears a passage for the bearing wheels. No crossing is placed on a steeper gradient than 1 in 10.

Locomotives.—These were built by the Schweizerische Locomotiv und Maschinenfabrik of Winterthur, Switzerland. They weigh 13 tons $5\frac{1}{2}$ cwt. when empty, and 17 tons $5\frac{1}{2}$ cwt. when in running order with full load of coal and water. They were guaranteed to be capable of driving a load of 18 tons up a gradient of 1 in $5\frac{1}{2}$ at a speed of 6·7 kilometres per hour. Their I.H.P. is 166. The cylinders are 300 millimetres in diameter, and they are placed outside the frame. The stroke is 600 millimetres. The motion is communicated to the cranks by means of a one-sided rocking lever with upper and lower connecting-rods. The throw of the cranks is thus reduced and tractive power increased. The fulcrum of the rocking lever is kept as low as possible. The valve-chests are above the cylinders. There are three axles, the leading and second each having pinion-wheels attached, and being coupled together, while the third is on a trailing pony-truck.

The wheels are carried inside the frames, and are all loose on the axles except one of those on the trailing axle, which is keyed. The first and second axles have solid forged disks in their centres; to each of these disks are attached two steel pinion-rings, so set that their teeth alternate. There are fifteen teeth to each pinion-ring. In order to hold these pinion-rings in their relative position on the axle disks, and yet at the same time to allow some slight circumferential movement to prevent jarring, and also to allow for

any slight irregularity in the pitch of the teeth of the rack-bars, eight double horseshoe springs are inserted in the disk under each pinion-ring. The upper ends of these springs project into countersunk spaces on the inner or under side of the rings. The maximum of play allowed is 3 millimetres, and to avoid more play being obtained in the event of one of these springs snapping or becoming weak, a solid iron tongue is introduced. The springs and pinion-rings are held in position by the brake drums (which will afterwards be described), being placed on each side, and being firmly bolted through the solid forged axle disks with eight steel bolts $1\frac{1}{8}$ inch in diameter.

The teeth of the pinions on the leading axle are given a lead over those on the second axle of one quarter the distance between two teeth, in order that when the teeth of a pinion on the leading axle are about to leave engagement with the rack, the teeth of the corresponding pinion on the second axle are about to engage. Perfect and continuous engagement is thus secured. In order to keep the water-level over the crown of the fire-box as regular as possible, the whole boiler is set down by the head at a slope of 1 in 11 to the horizontal. The gauge glasses are placed half way along the boiler, so as to register correctly on the varying gradients.

The boiler-plates are of mild steel, the fire-box is of copper with a circular top, and the tubes are of steel, with copper ends at the fire-box end. The water-tanks are on either side of the boiler, and run the whole length of the same. The leading dimensions of the engines are given in the Table on page 272.

A most careful test was applied to samples of all the materials used in the construction of these engines. The cost of the engines averaged about £1,475 each.

The two grippers are placed one in front of the leading axle and the other between the first and second axles in the centre of the engine.

Brakes.—There are five brakes on each engine:—Two separate hand-brakes, one steam-brake which can be applied by hand, one automatic-brake, and one air-brake.

Hand-brake.—On each of the driving axles (on each side of the pinions and securely bolted direct on to the axle disks previously referred to) are two deeply grooved cast-steel brake-drums, upon which grooved cast-iron brake-blocks work, one on each side of each drum, thus there are four drums with eight brake-blocks, the working face area of each block being 60 square inches. These

blocks are actuated by hand from the cab, there being two handles, one for the driver, which operates the four blocks on the right-hand side of the engine, and one for the fireman, which operates the four blocks on the left-hand side.

Steam-brake.—In addition to the hand arrangement above described, the four blocks on the right-hand side of the engine are capable of being worked by steam, the driver being able to bring them into action by means of a hand-lever rod, conveniently placed over the crown of the fire-box.

Automatic-brake.—This is a brake which is designed to come into action automatically in the event of an engine travelling, from any cause, above a given speed. On the right-hand side of the frame plate is placed a circular cast-iron box, which is connected on to a small shaft which passes through to the inside of the frame plate and is there geared by means of toothed wheels direct on to the leading axle. Within the circular box is a governor block, to which a light coil spring is attached; this spring is controlled by a screw which may be tightened or loosened, and thus regulates the action of the governor-block. On the maximum or limit of speed allowed being exceeded, the nose of this governor-block projects sufficiently far to strike a trigger, which on being tripped releases a powerful coil spring, and this, in its turn, pulls down a rod which opens a cone valve, and steam is admitted gradually into the steam-brake cylinder, which is fixed on the inside of the engine-frame. This arrangement has to be most carefully adjusted and constantly tested, as it is absolutely essential that the action of this brake should not be sudden, as locking of the pinions too suddenly must be carefully avoided on such gradients as those on the Snowdon Railway. Before the engine can proceed, after this brake has come into action, it is necessary for the driver to leave the cab and put the lever back in position and reset the trigger and so cut off the ingress of steam.

Air-brake.—This brake is used to control the engine while descending the mountain. Air is admitted to the cylinders through the exhaust ports, and on becoming compressed controls the travel of the piston. The driver, in order to allow the engine to descend, allows the compressed air to escape through a hand-valve, which is conveniently placed at the rear of the cab. All steam is cut off when the engine is descending, and when the air-inlet to the exhaust ports is open the passage for the steam exhaust to the chimney is closed. To avoid excessive wear and tear, water

is taken into the cylinder along with the air, from a spray pipe. This brake is most effective in its action, completely controlling the engine without the aid of other brake power, as long as everything in connection with it is kept in absolute repair, and all leakage is reduced to a minimum.

The Author at first found it extremely difficult to control accurately the speed at which the drivers allowed their engines to travel; he therefore had "speed indicators" attached to each engine. These instruments indicate the speed by a hand on a plain dial face, and in addition ring one beat on a gong to warn the driver that he is approaching his limit of speed, and three beats when he has reached or exceeded that limit. These indicators also register, by means of pin-pricks on a paper roll, the variations of speed during the journey, and so an accurate record can be kept of each driver's performances. The instrument has the appearance of a clock and is fixed on the top of the right-hand side water-tank, and directly facing the driver. A down shaft runs from the indicator, through the tank, to a box or case which is supported by bolts to the engine frame; within this box are a pair of mitre wheels, one keyed to the down shaft, the other to a short shaft which projects through the side of the box, and at the end of which is a crank with a long slot. This crank is worked by a projecting pin connected to the crank of the second driving axle, the revolutions of the axle being thus transmitted to the indicator. The engines are fitted with right- and left-hand re-starting injectors and sight lubricators for the cylinders and valve-chests; there is also an oil dripper arrangement in the cab which conveys a heavy lubricating oil direct to the teeth of the pinion wheels, but this is not sufficient in itself, and it is therefore essential that the rack-bars should be kept thoroughly lubricated. If this is carefully attended to there is little wear and tear on either the pinion wheel or the rack, considering the work these engines have to accomplish during a season.

The coal-consumption is heavy, the quantity used varying considerably with the load taken up and the quality of the coal. Unfortunately this last year, owing to trade complications, no really reliable tests could be carried out; but it is a fair average to say that from 6 cwt. to 7 cwt. of good-quality quick-steaming coal is burned on one journey.

The carriages are 38 feet long over buffers, 6 feet 6 inches wide and 9 feet 4 inches high; they are open at the sides above the door-level, and are divided into seven compartments, each

holding eight persons, and a separate compartment in front for the guard.

Canvas curtains are provided for use in wet weather, hung on slender wooden rods, which would snap under very severe strain from wind. In order to obviate any discomfort to the passengers, owing to the gradients up which the carriages have to pass, the upper seats in each compartment are deeply hollowed on the sitting portion; by this simple arrangement the necessity of stepping the floor of the carriage, or having movable seats, has been avoided. The weight of each carriage is 5 tons 13 cwt. now that grippers have been fitted similar to those on the engines. The under frame is of light sections of channel steel. The two four-wheeled bogies are spaced 28 feet centre to centre, the wheel base of each bogie being 4 feet; the wheels are of cast steel on steel axles.

On the rear bogie in each carriage is a double brake-pinion, which is carried on a separate short axle in the centre of the bogie frame, between the two bearing axles, and to the outer sides of which are bolted two grooved brake drums, on which four cast-iron brake-blocks operate. These blocks are applied by hand by the guard, from his compartment at the front end of the carriage, by means of a wheel. This brake arrangement is similar to the hand-brakes on the locomotives. The claw, or gripper, is carried at the back of the rear bogie. The centre of gravity of the carriages has been kept as low as possible, in consequence of the strong and gusty winds experienced on the mountain. A carriage with its full complement of passengers is calculated to withstand a wind-pressure of 36 lbs. per square foot. No couplings are ever used except to draw carriages out of the sheds.

The goods wagons are 12 feet long and 6 feet 3 inches wide, the sides being 11 inches deep. The under frames are of channel steel and the wheels and axles of steel; the distance from centre to centre of wheels is 7 feet, and each wagon is constructed to carry 6 tons. A platform is provided for the conductor, with a hand- or guard-rail, to which the brake-wheel is fixed. The wagon brake is similar in action to those on the carriages, but the pinion-wheels and brake-drums are attached direct to the rear axle.

The brakes, both on the carriages and wagons, are exceedingly powerful in action, completely controlling the carriage when applied on the steepest gradient. They are never applied except in case of emergency.

The following Table gives the leading dimensions of the locomotives in the maker's measures, with the English values appended :—

ENGINE.		
Diameter of cylinders	300 millimetres.	11 $\frac{1}{8}$ ins.
Stroke of piston	600 „	1 ft. 11 $\frac{1}{8}$ ins.
Diameter of pinion wheels at pitch } circle	573 „	22·56 ins.
Pitch of teeth	..	4·72 „
Diameter of rail-wheels on coupled } axles	653 „	25·71 „
Diameter of truck-wheels	520 „	20·74 „
Wheel base, rigid	1,350 „	4 ft. 5 $\frac{1}{2}$ ins.
„ total	3,000 „	9 ft. 10 $\frac{1}{2}$ ins.
BOILER.		
Number of tubes	156	..
Inside diameter of tubes	32 millimetres.	1·26 inches.
Outside „ „	35 „	1·38 „
Heating surface, fire-box	3·90 square metres.	41·981 sq. ft.
„ „ tubes	33·00 „	355·220 „
„ „ total	36·90 „	397·200 „
Grate area	0·95 „	10·030 „
Steam-pressure when at work . . {	14 kilograms per square centimetre.	200 lbs. per square inch.
Hydraulic-test pressure	20 „ „	284·4 „ „
Plates, cylindrical shell	11 millimetres.	0·43 inch.
„ copper fire-box	14 „	0·55 „
„ tube plates {	25 „ and	0·98 and
	20 „	0·79 inch.
Feed-water in tanks	1,700 litres.	374 gallons.
Cooling water for brake	300 „	66 „
Coal-box capacity	500 kilograms.	10 cwt.
Water in boiler	1,150 litres.	253 gallons.
Coal in fire-box, and tools	400 kilograms.	881 lbs.
Maximum load per axle	6,000 „	5·90 tons.
Tractive power	7,100 „	7 „