May 19, 1863.

JOHN HAWKSHAW, President,
in the Chair.

THE following Candidates were balloted for and duly elected :—
WILLIAM NEILL and GEORGE SMITH, Junior, as Members;
FRANCIS FOWKE, Captain, R.E., ALGERNON JOY, ARTHUR WILLIAM
STIFFE, JOSEPH HENRY TUCK, and WILBERFORCE WILSON, as
Associates.

No. 1,095.—“On the Manufacture of Duplicate Machines and
Engines.” By JOHN FERNIE, Assoc. Inst. C. E.

THE block-making machinery, designed by the elder Brunel for Portsmouth Dockyard, was nearly the first introduction of that system of special machines, each adapted to perform a particular operation, which may be said to have culminated so successfully in the Small Arms Factory at Enfield. Shortly before Brunel's day the factory system had been established, in which one machine shook out the impurities of the material, another spread, a third twisted, and a fourth spun; but there was no similar arrangement as applied to such refractory materials as wood and iron. In the year 1851 a great impetus was given to the extension of this system in Great Britain. It then became more generally known, that the Americans had established factories for the making of locks and fire-arms, and had, by means of the Blanchard lathe, and of a system of copying from patterns, greatly advanced in the manufacture of duplicates.

In Mr. Beamish's “Life of Sir M. I. Brunel,”¹ it is stated, that a saving was effected by the introduction of the block machinery of about £20,000 per annum; that four men, with the machinery, could make as many block shells as fifty men could produce without it, and that, in making the sheaves, six men could do the work of sixty; so that ten machine-men could do the work of one hundred and ten workmen. Another important result was that the blocks were duplicates of one another, and the parts were interchangeable.

In the year 1855 the old establishment at Enfield was broken up, and a new one was formed for the purpose of making rifles of the 1853 pattern, on the system established in America. The accounts for the year 1859-60 show, that the number of rifled

¹ *Vide* “Memoir of the Life of Sir Marc Isambard Brunel.” By R. Beamish, F.R.S. 8vo. Lond., 1862. Page 97.

muskets which had then been delivered into store was 87,405, on which there had been expended a total sum of £178,588 10s. 7d., being at the rate of about £2 1s. 8½d. per arm; while the contractor's price for the same, at £3 3s. 8d. per arm, would have been £272,509 5s.; thus, a saving had been effected of £93,920 14s. A proper allowance for depreciation on tools and buildings was made, and no money value is claimed by the Enfield authorities on account of the arms being duplicates of one another. It is only necessary to see a rifle put together at Enfield thoroughly to appreciate the mechanical advantages of the duplicate system. Thus, the separate pieces which form the lock are picked up indifferently from heaps of such pieces, every one fitting into its place most perfectly; and a rifle, the parts of which have never been together before, is formed in a few seconds from a lot of fittings promiscuously thrown together, as any lock will fit any stock, any stock will fit any barrel, and each part, however minute, will fit any rifle. If any part be broken, or requires replacing, there is a new one which will exactly fit it, so that wherever troops are armed with the Enfield rifle, there is not any fear of a mischance through a bayonet not fitting, and the armourer's duty is confined to the exchange of a few duplicate cocks or springs; and, as it is only a system of exchange, a skilled armourer may be dispensed with. Whether serving in Canada, India, or China, the various parts of that delicate instrument can be sent from home, with the certainty that they will fit the places for which they are intended, and thus there is a great saving of time and money, and the soldier is inspired with confidence in his rifle by the knowledge that it can be quickly made as good as new. It is no part of the Author's intention to describe the machines employed at Enfield. The parts of the rifle being small, special machines are adopted. These examples are only intended to show, that the system of duplicates both cheapens and improves the manufacture of all articles to which it can be applied.

Until lately, little or nothing had been done in the application of this system to the manufacturing of machines, or engines on a large scale. It is true the principle had been acknowledged, and various writers had urged the desirableness of its introduction into the railway system; but with such large component parts special machines were out of the question, and the only other possible mode was working to a correct standard. In the year 1840, Mr. Whitworth (M. Inst. C.E.), of Manchester, read a Paper at the meeting of the British Association in Glasgow "On Plane Metallic Surfaces, or True Planes;"¹ in 1851, at the Great Exhi-

¹ Vide "Miscellaneous Papers on Mechanical Subjects." By J. Whitworth, F.R.S. 8vo. Lond. 1858. Page 3.

bition in Hyde Park, he exhibited a machine for obtaining accurate minute measurements by touch; and at meetings of the Institution of Mechanical Engineers at Glasgow, in 1856, and at Manchester, in 1857, he advocated the adoption of a system of measurement for mechanical engineering work, in which the inch was to be the basis, sub-divided into a thousand parts for the finer dimensions. In these Papers¹ Mr. Whitworth demonstrated, most satisfactorily, the importance of fine measurements, and by models he showed that the thousandth part of an inch was not only an appreciable quantity, but that in a great many cases that difference was what constituted a bad fit.

The Author had long been satisfied, that the mode of taking dimensions in the workshop was far behind the times. A long and carefully graduated rule was considered the standard, and was used for setting out some of the work; but its application in the workshop was out of the question. The workman's rule was the real standard; and a bare $\frac{1}{16}$ th, or a full $\frac{1}{32}$ nd, of an inch embraced a very wide field indeed, extending to the shrinking on of a tire, or to the boring out of a wheel. With the sanction of Mr. Kirtley, the locomotive superintendent of the Midland Railway, the Author established a system which has, during the last five years, proved most beneficial, not only in reducing the cost of the work, but in greatly improving it, and at the same time perfecting the only plan by which all the parts of engines become duplicates of one another. At first a small machine, made by Mr. Cocker, of Liverpool, from Mr. Whitworth's gauges, was used; but it was soon found, that a larger and better machine was required. The system of end measurement with a gravity piece, as invented by Mr. Whitworth, was then adopted, and the machine first made took in 12 inches; but this also was found to be insufficient, and it was lengthened out to receive 100 inches. This machine consists of a strong bed plate (Plate 22, Figs. 1 to 7), having a V groove planed throughout its whole length. At one end there is a headstock, through which a square spindle, which fits the groove, is propelled by a hand wheel, which forms the nut of a screw having ten threads to the inch. This nut is in two parts, and can be tightened up by screws, so as to prevent any lateral play; and a collar and washer, also adjustable, prevent any play in the headstock. The other end of the bed has also a headstock and a screw movement, so as to adjust the length of the pieces in the groove, and to bring the readings of the index to 0. The difference between this machine and Mr. Whitworth's is in the way the subdivisions of the inch are obtained. In the Whitworth machine a screw, with exactly ten threads to the inch, is first made; whereas in this machine, as

¹ *Ibid.*, pages 39 and 57.

a screw could not be found with exactly ten threads, it was necessary to run a thread on the face of the hand wheel, and to sub-divide this for the length required for an inch.

The manner of obtaining duplicates with such a machine is very simple. First, a piece of metal exactly one inch in length is cut, and from it a second piece is made in the machine, by means of the gravity piece; then pieces, 3, 4, 5, 6, of 2, &c., up to 100 inches are cut. These sizes are now kept as duplicates. The finer dimensions are read from the divisions on the wheel, and from these, gauges for the use of the workshop are now made. All dimensions are thus duplicate multiples, or divisions of an inch, and a bare one-sixteenth of an inch becomes not an unknown quantity, variable with the rule or the eye of the workman, but so many thousandths of an inch, which are stamped on the gauges, and are soon understood. One of the first applications of the system in the workshop was to establish the necessary degree of tension required to insure the perfect fit of a wheel on its axle. Two workmen were directed to make a pair of male and female 6-inch gauges for this purpose; the one allowed $\cdot 012$ of an inch, the other $\cdot 003$ of an inch, taking the larger dimension first, and gradually reducing the difference. The experiments gave the following results:

EXPERIMENTS ON DIFFERENCES in DIAMETER in Boring and Turning WHEELS and AXLES.

No. of Experiment.	Length of Boss.	Diameter of Boss.	Diameter of Axle.	Difference in Diameter.	Permanent Stretch of Boss.	Remarks.
	Inches.	Inches.	Inches.	Inch.	Inch.	
1	7.0	5.988	6.000	0.012	0.006	Very tight. After pressing off, wheel and axle cut and slightly taper.
2	7.0	5.992	6.000	0.008	0.004	
3	7.0	5.995	6.000	0.005	0.002	
4	7.0	5.995	6.000	0.005	0.003	Very smoothly bored and turned.
5	7.0	5.997	6.000	0.003	0.000	Ditto; rather too easy a fit.
6	7.0	6.495	6.500	0.005	0.001	<div> <div> Axle slightly taper; diameter at 1.5 inch from outer end . . . 6.498 inches. </div> </div>
7	7.0	6.493	6.500	0.007	0.003	Tight. Ditto " " 6.498 inches.
8	7.0	6.491	6.500	0.009	0.005	Very tight. Ditto " " 6.497 inches.

From this Table it will be seen, that with a difference of $\cdot 005$ of an inch in the dimensions, there is a very small, permanent set in the wheel boss, but with a difference of $\cdot 003$ of an inch the set is hardly perceptible. It was found, however, that with ordinary lathe work, $\cdot 003$ was rather too fine a dimension, as lathes are seldom exactly true in their spindles, some boring slightly taper, and some an oval hole. The size $\cdot 005$ was finally adopted, and for

some years past all the wheels and axles have been adjusted to those dimensions.

In shrinking on outside cranks it was found, by a series of experiments similar to the above, that a difference of $\cdot 015$ of an inch was amply sufficient to retain them in their places, the old allowance being $\cdot 030$ of an inch; while crosshead spindles, of $2\frac{1}{2}$ inches diameter, pushed into their places by hydraulic pressure, require a difference of $\cdot 004$ of an inch; and levers with 3-inch holes require a difference of only $\cdot 001$ of an inch, when they have to be driven into their places with a lead hammer. All these dimensions were previously empirical; but with this system of working they become known quantities.

The gauges used are exceedingly simple. Each consists of a piece of steel about 1 inch wide, parallel in the width, two-eighths of an inch thick in the middle, and tapered towards the ends, which are rounded. Each gauge is made nearly to the required length. The ends are then hardened, and the bar is brought to the correct standard by a whetstone. This gauge should just pass through the eye of a wheel. The gauge for the shaft is of the horse-shoe shape, and is made of steel, with the ends hardened. For wheel work, the lathe men have copies of these gauges, and the foreman of the press-shop has also copies, and it is his business to try if the wheels and the axles are turned to the gauges, and if they are not correct, to reject them. It will be seen from this, how accuracy is not only easy of attainment, but how it is checked. There is no difficulty in this way of working; it has been in use for years, and a misfit is unknown. The valve motions of locomotive engines having to sustain a great deal of wear, from the speed and pressure on the backs of the valves, the pins and joints require to be carefully fitted and case-hardened, after which they are ground to fit their places. While exposed to the carbonizing process, the pins expand and the joint-holes contract. With the measuring-machine, this expansion and contraction is easily found, and an allowance being made for it in the boring and turning, only the smallest amount of "lapping" out is required, and a great deal of grinding is saved.

Plate 22, Figs. 9, show how the lengths of the eccentric rods are preserved uniform. A is a hollow casting, supported on legs, and being about the same height as a workman's bench. This casting is planed on three sides, and two castings, D D, which are facsimiles of the eccentrics, are bolted on at one end. At the other end two jaw-pieces E E are bolted on, corresponding to the position which the links bear to the eccentrics. The workman first scrapes the eccentric straps to D, and the joint is then brought down over the jaws E E, and the pin F must pass through the joint and the jaw-piece. The rod is now perfect as regards length, nor can there be any twist in the joint or pin, and the strap and rod are now

ready for hanging on the engine from the hands of the fitter. Plate 22, Figs. 10, show how the key groove is cut in the outside cranks. A strong casting A, has its top and bottom surfaces and the top of the lugs B planed; a wrought-iron plate C is then fastened to the lugs B, and the tool being taken to the lathe, the holes D and E are bored in it. The key bed and hollowed-out part in C are carefully set out, and after being cut, the plate is case-hardened, and a large pin F is turned to fit the holes. The crank H is pushed through between the surfaces A and C, until the crank-pin fits the hollow part in C. The pin F is then pushed into its place, and the set screws being brought down on the crank, the work is ready for slotting. The eccentric key grooves are cut in a precisely similar way; no setting out is required, and there is no chance of any mistake from the carelessness of the workmen. The cranks and eccentrics must be exact, or they will not fit these tools, and thus a certainty is attained in the depth and the position of the key groove. The corresponding templates for cutting the grooves in the axles are shown in Plate 22, Fig. 8.

Considerable improvements have been effected in plate-moulding during the last few years, and no system of machine-making would be perfect, without their application in the foundry. The plan adopted at the Midland Railway works at Derby is not new, but it is believed to be its first application to such large and complicated castings as locomotive cylinders.¹ Plate 22, Figs. 11 to 17, show how the cylinders are moulded. Fig. 11 shows one-half of one of the patterns ready for moulding. A is a hollow-plate casting, the surface of which is planed for the half pattern to lie upon; eight small strips on the edge of this plate are also planed, to fit a large template, which has four holes in it corresponding to the pins D D. The moulding boxes have corresponding strips on all their edges, and after their joints are planed, these strips are planed to fit the same template; all the pin holes for the plates and the moulding boxes being drilled with a pin drill from the template. Centre lines are also run on the boxes and the plates from centre lines on the template, and the half patterns are then attached to the plates by pins, the centre lines on the patterns corresponding to the centre lines on the plates. Fig. 12 shows how the steam chest is moulded. A is a planed surface plate as before, and a pattern, representing the surface of the steam chest, is inserted in it at M, as shown in plan, Fig. 13, and two elevations, Figs. 12 and 14. The moulding box is dropped on the pins D D, and the sand is rammed up as usual, after which the box is ready for the drying stove. Figs. 15, 16, and 17, are longitudinal and transverse sections of the moulding boxes, fixed together ready for casting.

¹ Moulding boxes for axle brasses were exhibited at the Meeting.
[1862-63. N.S.]

The core barrel G has strong castings at each end II II, which are bored for the spindle K H K, and are turned on the outer edge to fit the moulding boxes. The middle part of the core barrel is a wrought-iron plate, pierced with holes, on the outside of which is shown the hay-band and the core. The four different box parts are shown at C 1, C 2, C 3, and C 4. Box C 1 is moulded from a plate as shown in Fig. 12. Boxes C 2 and C 3 are moulded from half patterns as in Fig. 11. These two boxes C 2 and C 3 have their ends carefully bored out from the centre lines to fit the turned parts of the core barrel, so that the weight of the core is not sustained by the sand, but rests on the metal of the box part. C 4 is moulded on a plate similar to Fig. 12, and requires no especial description. The steam and exhaust cores are moulded in cast-iron core boxes, carefully fitted on the inside, and the cores are placed in the stove in their own boxes, and by that means are free from twist, and are accurate in length and shape. As will be seen from the sections, a minimum quantity of sand is used, and the projecting pieces cast on the boxes do away with all lifters. By this mode of moulding, the castings come cleaner from the sand, the patterns are not knocked to pieces by rapping, the cylinders are perfectly true in the bore and passages, and at the same time the manufacture is brought within the grasp of any man who can throw in the sand and ram it. Fig. 16 shows partly an end elevation, and partly a section, of the boxes fitted together; the holes O O O being for pouring in the metal and for the rising head.

It would be tedious to describe the different templates and gauges used in completing the various parts of a locomotive engine made on this system. It will be sufficient to say, that each separate part is as carefully fitted as those already described, and that all the dimensions are obtained from duplicate templates, representing inches and parts of an inch, to three places of decimals.

Plate 23, Figs. 1 and 2, show the first step in fitting together the various pieces, so as to insure uniformity in erection as well as in construction. A is a large surface plate, strengthened by deep ribs and bars, the surface and edges being planed. Two brackets B B are bolted to this plate, and have all their faces and edges planed. The cylinders, after being fitted together, are placed on the two brackets, the parts on which they rest being also planed. The two brackets C C have recesses planed in them to receive the slide bars, and it is the duty of one set of men to fit the slide bars D D, the spectacle plates, the cross head and slide blocks, the piston and rod, the valve spindles, guides, and pumps. When all these have been fitted together, the next operation is to lift them on to the cradle C C, Plate 23, Figs. 4 and 5, which show the mode of erecting engines from a true plane, all the upright

lines being squared up from the beams A A, B B, the horizontal lines being obtained by a surface gauge working on the same true surfaces. The cradle C C is firmly fixed on the two cast-iron girders A A, about 30 feet long. Their upper surfaces, which are slightly above the floor of the workshop, are carefully planed, as well as the edges and the grooves which correspond to the edges of the rails. The planed lower edges of the cylinders, already described, rest on the planed surfaces of the cradle at the proper angle, and are brought to the centre lines on the cradle F F, by the set screws at E E. At the ends they are adjusted to lines which pass through the cylinders to the uprights S S, the longitudinal position being obtained by a straight edge laid on the face of the cylinders, corresponding with the planed surface on the front of the cradle, on which are drawn the centre lines. The inside frames L L are then attached to the cylinder; the holes of both being drilled to a template, only require rose-bitting, the end of the frame being supported by the upright at N. The outside frames J J are then attached, by means of the bracket plates and the buffer beams. As the pieces R R R correspond to the position and dimensions of the axle-boxes, all that is required is to describe on the horn blocks lines squared up from these pieces. These are then removed, and being planed to the lines, the boxes are fitted into their places; after which the wheels, motions, and rods, being hung on, the engine is run over another pit to have its boiler put on, an operation which does not require a special description.

It will be seen, from this description, how parts, however large, may, by this system of accurate measurement, become duplicates of one another, and can at any time be replaced; and that the parts become interchangeable, so that any part may be sent to a distant station, with the certainty of fitting when it arrives there. The advantages claimed are, first, economy in manufacture; secondly, greater perfection in workmanship; and thirdly, an accurate system of duplicates, whereby the parts become interchangeable. The Author especially recommends this system to the Engineers of Indian and Colonial Railways, and he sees no reason why the different parts of the engines and rolling stock sent to those places should not be as perfect duplicates, as the different parts of the Enfield rifle.

The communication is illustrated by a series of diagrams, from which Plates 22 and 23 have been compiled.

SURFACE PLATE FOR FITTING MOTIONS ON CYLINDERS.

MODE OF ERECTING ENGINES FROM A TRUE PLANE.

Floor line.