ON ELECTRO-MAGNETIC MACHINE-TOOLS.

By Mr. FREDERICK JOHN ROWAN, of Glasgow.

The Electro-Magnetic Machine-Tools devised by the author and forming the subject of the present paper are the result of his endeavour to overcome the difficulties of riveting the plating of ships by other means than hand labour. Many interesting attempts, commencing with the steam riveter of Mr. J. McFarlane Gray in 1863 (Proceedings 1865, page 129), have been made to introduce mechanical appliances into that branch of constructive engineering, with varying success. The conditions of the work itself involve the separation of the riveting or hammering portion of the apparatus from the bolster or holder-up, while on the other hand the conditions of the process of riveting require that the two portions of the machine should be rigidly held together; and in consequence of these conflicting requirements, the application of machine riveting to this class of work has not been a promising field for experiment.

Almost the only method hitherto possible of uniting the two parts of the riveting apparatus has been by bolting them together by bolts passing through the rivet holes. It has been found however that this requires too much labour and time; and it also leaves a number of vacant holes which cannot be reached by the machine, and must therefore be filled up and have the rivets closed by hand. One of the most successful of the machine ship-riveters was that introduced by Mr. John McMillan of Dumbarton in 1876. The necessity for very frequent shifting of the attaching bolts was obviated by having the steam striker carried on a horizontal slide, which was bolted at its ends to the side plating of the ship and embraced about the length of a plate; no method of mechanical holding-up was included in the plan. This arrangement however still left some rivets to be closed by hand; and continued to require manual labour for the holding-up, which has been proved to be the most severe portion of the riveter's work.* In spite of these drawbacks the machine did some excellent work, and proved to the satisfaction of the surveyors of the Board of Trade and of Lloyd's Register that the quality of the riveting done by machines in ship-building is superior to that of hand work, in so far as regards the filling up of the rivet holes, on account of the machine blows being much heavier and more direct than those given by hand hammers. The comparative efficiency of riveting done by different methods is dealt with in the appendix.

Electro-Magnetic Riveting.—The use of electro-magnets for the purpose of attaching the machine to its work satisfies the requirements in a very complete way. It gives a rapid method, practically instantaneous, of fixing the riveting portion of the machine to the work; and leaves no rivet holes to be afterwards filled up by hand. The bolster or holder-up is as quickly attached on the other side of the plating. When the magnets are properly arranged on opposite sides of the plating with the two poles of unlike denominations facing each other, they are drawn towards each other, thus pressing the plates together and ensuring the proper condition for riveting. The effect of bolting the two portions of the machine together through the rivet holes is thus obtained without any attendant drawbacks; and the distressing work of manual holding-up can be reduced to a minimum.

In Figs. 1 to 3, Plate 56, are shown two forms of the electro-magnetic riveting machine; AA are the holding-on magnets, and M the motor, which by means of the gearing G and cam C lifts the hammer H against a spring. The amount of compression imparted to the spring in lifting is regulated by the position of the disc or

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* See Dr. Barr's paper in the Proceedings of the Philosophical Society of Glasgow, vol. xvii, page 223.

piston D, which can be adjusted by hand by means of the screw spindles R and spur-gearing W; the same mode of adjustment is equally applicable where springs are used in tension instead of in compression. The striking mechanism may of course be worked by other means than the cams shown in Figs. 1 to 3. Hammers driven by steam, compressed air, water, or gas, can be used with holding-on magnets; or the motor may be apart from the magnets, and the power transmitted by flexible shafting. The same remark also applies to the driving of the rest of the tools subsequently described.

The holder-up is shown in Figs. 4 and 5, Plate 56; AA are the holding-on magnets, and the bolster or dolly B is kept to its work by the spring S, which compensates the flattening of the rivet-head during the operation of riveting. A curved arm or attachment E, Fig. 5, carries a small subsidiary bolster and spring, for insertion under the reverse bars of ships' frames or into confined spaces.

Drilling.—The application of the same principle to drilling, tapping, and other tools, became apparent to the author as soon as the idea had occurred to him of constructing a riveter in this way. The application to drilling is he thinks even more important than to riveting, and is capable of a wider range of employment; because while an electro-magnetic riveter must compete with hydraulic, steam, and power machines, where these are practicable, the case is different with regard to drilling. The want of suitable drilling tools for shipbuilding work has prolonged the continuance of the more imperfect system of punching; and the hand ratchet, which is in many cases the only alternative to the punching machine, is a very slow and inefficient appliance.

The importance of substituting drilling for punching in the preparation of structures composed of plates and bars of steel, and even of iron, has been, by inference at any rate, very fully established. The evidence is on record of many investigations which have been made since the year 1850 into the strength of riveted joints composed of both punched and drilled plates. The list is a long one, and shows that the best engineering talent of this country has been employed in the work. Professor W. Cawthorne Unwin has recorded all the principal memoirs on the subject prior to 1881* in his preliminary Report to the Research Committee of this Institution on Riveted Joints (see Proceedings 1881, page 303); while that Report and the accompanying and subsequent records of investigations by Professor Alexander B. W. Kennedy (Proceedings 1881, 1882, and 1885) completely summarise the existing information regarding the comparative effects of punching and drilling upon iron and steel plates, and regarding important collateral points. From a careful examination of the voluminous Tables given in Professor Unwin's Report, the results of the greater number of the experiments made on iron and steel plates lead to the general conclusion that, while thin plates, even of steel, do not suffer very much from punching, yet in those of ½ inch thickness and upwards the loss of tenacity due to punching ranges from 10 to 23 per cent. in iron plates, and from 11 to 33 per cent. in the case of mild steel. Mr. Parker has recently stated† the loss of tenacity in steel plates to be as high as fully one-third of the original strength of the plate. In drilled plates on the contrary there is no appreciable loss of strength. It is even possible to remove the bad effects of punching by subsequent rimering or annealing; but the speed at which work is turned out in these days is not favourable to supererogatory or multiplied operations, and as a consequence such additional treatment is seldom practised. These facts lead irresistibly to the conclusion that the introduction of a practicable method of drilling the plating of ships and other structures, after it has been bent and shaped, is a matter of very great importance. If even a portion of the 30 per cent. deterioration of tenacity can be prevented, a much stronger structure results from the same material and the same scantling. This has been fully recognised in the modern practice of the construction of steam boilers with steel plates: punching in such cases being almost entirely abolished, and all rivet holes being drilled after the plates have been bent to the

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* In the appendix to the present paper are mentioned subsequent memoirs that have appeared since the date of Professor Unwin's list.

† Transactions of the Institution of Naval Architects, 1886, p. 133.

desired form. The magnitude of the interests which are dependent upon the strength and therefore upon the security of ships is little, if at all, less than that of those which are affected by boiler safety.

Electro-magnetic drilling machines offer practically the same facilities for the work of shipbuilding and for other operations as are already possessed in boiler-making; but they differ from the drilling machines used in the latter process in this respect, that in using the electro-magnetic drilling machines it is necessary to move only the smaller weight of the machine, instead of the larger weight of the boiler or other structure. This of course renders them applicable also to boiler-making and other engineering work.

In Fig. 6, Plate 57, is shown a simple form of drilling machine, in which AA are the holding-on magnets, M the motor, D the drill spindle, and F the feed of drill. After several trials of other forms, it has been found better to work either hammer or drill through an opening cut in the centre of the yoke joining the two magnet cores, and to have the hammer-shaft or drill-spindle between the magnet poles instead of beyond the line joining their centres. The thrust of the hammer or drill is thereby distributed equally over both magnet poles. In some exceptional positions however, convenience of working requires other forms; and machines may be made which will work satisfactorily, although the above arrangement is departed from. An instance of such alteration in form is given in Fig. 7, which illustrates a drilling machine now at work with good results, the drill projecting beyond the magnets. Multiple and radial drilling machines and several other kinds of machine tools have also been designed on this system.

In Fig. 8, Plate 58, is shown the magnetic attaching apparatus, combined with a drilling machine worked by hydraulic power on M. Marc Berrier-Fontaine's plan, or by steam or compressed air in a Brotherhood three-cylinder engine.

Tapping.—The operation of tapping stay-bolt and other holes can also be carried out rapidly by power by means of electro-magnetic machines, instead of very slowly by hand as at present. The use of an electro-motor for working the tapping bar has the advantage that its direction of motion is easily and quickly reversed, as is requisite for the rapid withdrawal of the tapping bar. In Fig. 9, Plate 58, is represented a tapping machine which is similar in general design to the drilling machine shown in Fig. 6. No feeding screw is required in this case, as the tapping bar T feeds itself forward as soon as a thread is formed. Consequently only a lever L is provided, for giving the needed pressure on the head of the tapping bar in order to start the cut.

Caulking and Chipping.—These operations are also quite under the control of electro-magnetic machines. Frames to serve as guide-bars are attached to the work by electro-magnets or otherwise, in such a position that a long range of seam or surface is commanded by the machine when moved along these guides. The chipping or caulking tool is regularly and quickly struck by a power hammer, which is worked by an electro-motor or by a solenoid or otherwise, as is convenient. In Figs. 10, 11, and 12, Plate 59, are shown forms of caulking and chipping tools, that in Figs. 10 and 11 being worked by a small motor, and that in Fig. 12 by solenoids. An electro-magnet is shown attached to each of these tools; and in Fig. 17, Plate 60, is shown the guide-bar arrangement, by means of which the tools without holding-on magnets can be moved along through a considerable range.

A general idea is given in Fig. 14, Plate 59, of the application of the tools to the side plating of a ship, with the individual machines held on by their own magnets; while Fig. 15, Plate 60, showing part of the side plating in sectional plan, illustrates several tools working on the same guide-bars or frame, one being a steam-riveter, one a spring-hammer, worked by an electro-motor, and one an electric hammer worked by solenoids. The frame or guide G is further shown in Fig. 16; and at JJ in Figs. 13 and 14, Plate 59, are shown guide-bars attached to the bottom of a ship, for facilitating the handling of the hammer or other tool, as lifting tackle could not readily be applied in such a position. When the holding-on magnets of the tool are released, the tool drops down on the guide-bars, along which it can then be shifted; and the attractive force of the magnets is sufficient to raise it back again to its working position.

Practical Results.—With a view to ascertaining practically the conditions essential to successful work, one or two trial machines were constructed, which although imperfect were useful in enabling experience to be acquired of the kind desired. The first successful examples are the electro-magnetic machines introduced by Mr. John McMillan, Jun., into the practical work of his ship yard, from which on 19 May 1887 was launched the s.s. "Albania," having a portion of the rivet-holes in her shell drilled by these machines. After a very small amount of practice the men working the machines drilled the $\frac{7}{8}$-inch holes in the shell with great rapidity, doing the work at the rate of one hole every 69 seconds, inclusive of the time occupied in altering the position of the machines by means of differential pulley-blocks, which were not conveniently arranged as slings for this purpose. Repeated trials of these drilling machines have also shown that, when using electrical energy in both holding-on magnets and motor amounting to about $\frac{3}{4}$ H.P., machines of the form illustrated in Fig. 6, Plate 57, have drilled holes of 1 inch diameter through $1\frac{1}{2}$ inch thickness of solid wrought-iron, or through $1\frac{5}{8}$ inch of mild steel in two plates of $\frac{13}{16}$ inch each, taking exactly $1\frac{3}{4}$ minute for each hole. The machine illustrated in Fig. 7, which has magnets of less holding power, when using only about 0·6 H.P. of electrical energy took the same time to drill holes of $\frac{11}{16}$ inch diameter through wrought-iron of $\frac{13}{16}$ inch thickness. As regards speed of drilling, the author believes these results are equal to any obtained by machines using much greater power.

With the hammer shown in Fig. 1, Plate 56, using an electro-motor giving out $\frac{1}{2}$ brake H.P., from 100 to 150 blows per minute have been obtained, with a force of impact equal to about 180 foot-lbs. per blow, as nearly as could be ascertained. This is much greater than the force of blow given by hand hammers weighing 6 lbs. and striking as heavily as is possible in staving up. At the works of Messrs. Immisch in March last, this riveter was seen closing 1-inch rivets in 10 seconds each.

The electro-motors used by the author in the machines constructed for Mr. McMillan, with which these results have been obtained, were of Messrs. Immisch's design and manufacture; and the author believes they will not readily be surpassed.

After seeing the machines at work in Messrs. McMillan's yard, Messrs. William Denny and Brothers constructed an electrical drilling machine having a modification of the traversing frame illustrated in Figs. 13 and 15, Plates 59 and 60, but without holding-on magnets; and applied this machine to drilling the rivet holes in the butt joints of a large steamer. The drilling machine illustrated in Fig. 6, Plate 57, has also been successfully used for drilling holes of $1\frac{1}{4}$ inch diameter in the engine-seat of the s.s. "Pukaki," under the direction of Mr. Archibald Denny, of whose co-operation and assistance the author has had the benefit in the early working of his machines.

In designing the earliest machines on this system the author was without any data which were of use as a guide in determining sizes of electro-magnets or of electro-motors for the various requirements of different machines. Most of the investigations into the elements of electro-magnets have hitherto been directed to questions affecting their use under the conditions found in dynamo machines. Consequently expressions of their efficiency, which are to be found in published treatises, are given in terms chiefly of the intensity of the magnetic field, and not with reference to their holding, or, as it is called, lifting power, which is the quality made use of in the machines here described. From a number of experiments which he has made with apparatus of different dimensions, the author has however obtained results which promise to yield the elements for the statement of a general law for the construction and holding power of electro-magnets. This investigation is not yet completely worked out, but it is under consideration; and the author reserves an account of it, together with further results from the working of the machines now described, for another paper.

The introduction of these electro-magnetic machines presents also some interest from an economic point of view, in addition to their practical advantages in carrying out engineering work. Until now the shipbuilding industry of this country has been to a great extent controlled by the trades union of the riveters, so that employers of labour have been unable always to regulate the cost of work as affected either by the rate of wages or by the speed at which the work was completed. This has told most heavily against them in busy times, especially when an abundance of work has followed quickly on a period of depression. Hence it is of great importance that they should possess such a means of controlling both the cost of the work and the rate of construction as the author believes is furnished by these electro-magnetic machines.

The subject of the present paper forms the threshold of the still larger subject of the electrical distribution of power for engineering operations in general; and the author believes it will be found both economical and otherwise convenient to adopt electrical distribution in engineering workshops, instead of the existing system of shafting and belts, or even hydraulic distribution of power.

APPENDIX.

Comparative efficiency of riveting done by different methods.

The valuable information on riveted joints recently presented in the excellent Reports of Professors Unwin and Kennedy to this Institution (Proceedings 1881, 1882, and 1885) goes very far to establish the four following points:—

1. That the shearing resistance of rivets is not highest in joints riveted by means of the greatest pressure;

2. That the ultimate strength of joints is not affected to an appreciable extent by the mode of riveting; and therefore,

3. That very great pressure upon the rivets in riveting is not the indispensable requirement that it has been sometimes supposed to be.

4. That the most serious defect of hand-riveted as compared with machine-riveted work consists in the fact that in hand-riveted joints visible slip commences at a comparatively small load, thus giving

such joints a low value as regards tightness, and possibly also rendering them liable to failure under sudden strains after slip has once commenced.

From a review of the evidence the author concludes that, provided the plates or other materials are held together with sufficient power during riveting and during the cooling of the rivets, and provided also there is brought to bear on the rivets (either by pressure or by heavy blows) sufficient force to ensure their being expanded so as to fill the rivet holes completely, then the best results as to ultimate strength and tightness of the joints will be realised, and no increase in either of these respects is to be expected from merely exceeding the necessary force.

Professor Unwin's Report on the form of riveted joints (Proceedings 1881, p. 329) contains the following:—"In Messrs. Greig and Eyth's experiments three strips were connected by a rivet so that the rivet was in double shear. The riveting was done by different machines, and then the rivet was broken by shearing. It appeared that the shearing resistance was highest with joints riveted by the machines which worked with the greatest pressure. With steel rivets $\frac{5}{8}$ inch diameter, in $\frac{11}{16}$ inch drilled holes, the pressure on the rivet when riveting and the shearing stress were as follows:—

	Pressure on Rivet. Tons.	Shearing Resistance. Tons per square inch.
Steam riveter	37	25·74
Stationary hydraulic riveter . .	39	23·80
Portable hydraulic riveter . .	20	22·78
Power riveter, light . . .	31	22·50
Power riveter, heavy . . .	52	23·76

"

Messrs. Greig and Eyth's conclusion, as to the connection between high riveting pressure and high shearing resistance, is however not supported by their own tabulated results; for the highest resistance, 25·74 tons per square inch, results from a riveting pressure of 37 tons obtained with a steam riveter which is only third in the ascending scale of riveting pressures. On the other hand the machine having the highest riveting pressure, or 52 tons, namely the "power riveter, heavy," gives joints with a shearing resistance of only 23·76 tons per square inch, or only third in an ascending scale of shearing resistances. Still further, the stationary hydraulic riveter, giving a pressure on the rivets of 39 tons, produces a shearing resistance in joints which is 2 tons per square inch *less* than that possessed by joints made with a pressure 2 tons less: and the portable hydraulic riveter giving a pressure of 20 tons produces joints of *higher* shearing resistance than the power riveter giving 31 tons pressure. It is evident that beyond a certain point there is no relation between pressure given by the riveter and resulting strength of joints. Professor Unwin evidently does not accept Messrs. Greig and Eyth's conclusions, for he remarks:—"If there is a real difference in the shearing resistance with different riveting pressures, it must be due to friction, or to some change in the strength of the material in the process of riveting. The difficulty in ascribing it to the former cause is this, that it is not probable that a red-hot rivet can retain the compression it receives from the riveting machine. It has hitherto generally been assumed that the clipping together of the plates which produces friction is due to the contraction of the rivet in cooling, and not to the pressure put upon it by the riveting machine. Mr. Kirk has recently shown to the Reporter some joints cut through after riveting. These appear to show that in thick plates a tighter joint is obtained by continuing the riveting pressure for a sensible period, instead of removing it at once as in ordinary machine-riveting. The point is not quite clearly made out, but it deserves further investigation. It does not seem at all impossible that thick plates may spring a little, while the rivet is still red-hot, and it would be very objectionable if this were really the case."

With regard to the point raised by Professor Unwin in the concluding portion of these remarks, it is evident that the result he desires to obtain can be secured by maintaining a pressure upon the plates themselves, instead of upon the rivet and plates. The maintenance of the pressure upon the plates themselves alone, while keeping them rigidly together, would at the same time give the rivet a better chance of cooling quickly.

The following figures of mean results, taken from Professor Kennedy's Tables 29 to 32 inclusive (Proceedings 1885, pp. 218–225), give a comparative view of hand and hydraulic riveting, as regards their ultimate strengths in joints, and the periods at which in both cases visible slip commenced :—

Total Breaking Load.		Load at which Visible Slip began.	
Hand Riveting.	Hydraulic Riveting.	Hand Riveting.	Hydraulic Riveting.
Tons.	Tons.	Tons.	Tons.
86·01	85·75 77·00	21·7	47·5 35·0
82·16	82·70 78·58	25·0	53·7 54·0
149·2	145·5 140·2	31·7	49·7 46·7
193·6	183·1 183·7	25·0	56·0 69·0

In these figures hand riveting appears to be rather better than hydraulic riveting, as far as regards ultimate strength of joint; but is very much inferior to hydraulic work, in view of the very small proportion of load borne by it before visible slip commenced.

It is important thus to learn that there is nothing inherent in the mode of riveting which interferes with the strength of the work: so that, if improved as regards tightness, riveting done by means of hammer blows would be as good as that produced by continuous pressure.

List of Memoirs on Riveting
subsequent to those enumerated in Proceedings 1881, *pages* 303–305.

"On Riveting, with special reference to Ship-work." By M. le Baron Clauzel, of Toulon. Proceedings Inst. M. E. 1881, pp. 167–204.

"Results of Experiments on Riveted Joints." By Professor Alexander B. W. Kennedy. Proceedings Inst. M. E. 1881, pp. 205–290, 712–721; 1882, pp. 138–143; and 1885, pp. 198–291.

Contributions as appendices to above and in discussion. By R. H. Tweddell, W. John, C. H. Moberly, W. Silver Hall, R. V. J. Knight, &c.

"First Report to the Council of the Committee on the Form of Riveted Joints." By Professor W. C. Unwin. Proceedings Inst. M. E. 1881, pp. 301–368.

Tests of Riveted Joints. By C. H. Moberly. Proceedings Inst. C. E. 1882, vol. 69, p. 337; and 1883, vol. 72, p. 226.

Forms of Test Pieces. By William Hackney. Proceedings Inst. C. E. 1884, vol. 76, p. 70.

"The Influence of Punching Holes in Soft Steel." By V. N. Beck-Guerhard. A series of experiments carried out at the Poutiloff Works, St. Petersburg. Journal of the Iron and Steel Institute 1884, pp. 290–295.

"The Influence of Holing upon the Strength of Wrought-Iron." By Professor L. Tetmajer of Zürich. Schweizerische Bauzeitung, 1886, p. 33. Abstract in Proceedings Inst. C. E. 1886, vol. 85, p. 421.

"The present Aspect of Mild Steel for Shipbuilding." By John Ward. Transactions of the Institution of Naval Architects, 1886, pp. 65–122.

"Report on the Effect of Punching, Drilling, and Riming Mild Steel Plates." By William Parker and William John. Transactions of the Institution of Naval Architects, 1886, pp. 415–422.

Discussion.

Mr. Rowan exhibited one of the electro-magnetic drilling machines which had been employed in the shipbuilding yard at Dumbarton.

Mr. T. Hurry Riches, Member of Council, said the employment of electro-magnetic machine-tools involved several points that deserved very careful attention. There was first the cost of the machine itself, and then the cost of the motive power. Another very important matter was the influence of the magnetism upon the ships, particularly those made of steel. As was well known, if any

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magnetic force was applied to iron, it became a temporary magnet, but ultimately lost its magnetism. It was not so however with steel. Everyone connected with shipping knew that there was a great deal of trouble in the adjustment of the compasses in steel ships, and that they suffered a great deal of disturbance whenever any riveting or hammering of the hull took place. It occurred to him that possibly the act of bringing to a steel ship a very powerful storage of magnetic force might practically convert the ship into a gigantic magnet, and being built of steel she would then become inevitably a permanent magnet. This was a matter that he thought should receive attention before such powerful magnets were used. With respect to boilers, it was well known that electricity exercised a very considerable influence, particularly on steel boilers, in regard to pitting; and electrical contrivances had been designed for the purpose of preventing the deposit of carbonate of lime and other objectionable substances on the surfaces of the plates, and in that way preventing injury to the boilers. The employment of electricity was therefore a question of importance, especially to steel boilers, owing to the fact that the steel became a permanent magnet when once magnetised. The introduction of additional magnetic influence to act upon the plates or other parts of a multitubular steel boiler suggested the probability that it would materially affect the action of the chemical constituents of the water upon the boiler during the remainder of its existence.

As to the removal of the machines from point to point, it was easy in a shop to deal with the question of transport; but alongside a ship he thought it would be a very long and troublesome process to have to de-magnetise and re-magnetise every time the drill or riveter was required to be adjusted to the next hole. No doubt a certain amount of time would be saved in the actual drilling or riveting; but to have to magnetise and de-magnetise such large magnets on every occasion appeared to him to be a very large item in dealing with the riveting of ships.

Mr. L. Sterne mentioned that he had worked at this subject some years ago, and referred to the paper read before the Institution in Birmingham (Proceedings 1875, page 38) on an electro-magnetic chuck for holding special work in lathes. At that time there was only one powerful dynamo in England, which belonged to M. Gramme, and had been brought over for experimental purposes. The greatest difficulty was experienced previously in getting the required magnetic power to last long enough with batteries only; they were not of sufficient duration to ensure success. In this connection he might add that he had found great advantage from agitating the batteries by means of an eccentric raising the plates out of the liquid at each revolution. Another great difficulty with drilling and cutting tools was that the magnetic power at the cutting edges of the tools attracted the disengaged particles of metal, interfering with work to such an extent that the tools had to be taken out and sharpened every few minutes. Perhaps the author had found the means of insulating the tools so that they should not be charged with such a strong magnetic influence at the edges.

Another difficulty which he had experienced was that the entire body and working parts of the tool—the planing machine, lathe, or drilling machine—had to be insulated. Otherwise, during work and for days afterwards, everything placed on the tool was attracted; and it remained, as Mr. Riches had pointed out, charged with residual magnetism so long that ultimately this system had to be abandoned as not practicable. It was however adopted for one purpose, where it answered very well, namely for grinding circular knives or discs which were so thin that no mechanical appliance could be made to hold them in the lathe. As mentioned in the paper referred to, while holding them on the magneto-electric chuck they were prevented from slipping by a small stud, and could then be ground with such precision for cutting the india-rubber threads for elastic webbing that when the thread was stretched to twelve times its normal length no trace of irregularity in thickness could be seen in it. The superiority of elastic webbing depended entirely upon the regularity of the cut thread. There was no other mode of doing such fine work; and that was the only use for which this magnetic appliance had ever been proved successful and continued in use at present.

Mr. R. PRICE-WILLIAMS, Member of Council, could entirely confirm the remarks of Mr. Sterne, whose former careful experiments and researches he had watched with great interest; and they had naturally recurred to his mind in connection with the present paper, from which he was glad to gather that the difficulties previously experienced had now been effectually surmounted. He should much like to hear how the attraction of the cuttings to the point of the tool had been got over; in the earlier trials this had proved so great a trouble that it had quite neutralised the advantage of the magnetic chuck.

With regard to the riveting machine shown in Fig. 1, Plate 56, he enquired whether the percussive action of the hammer blows on the rivet head had been found to produce any detrimental effect upon the steel rivets; he was under the impression that the time had arrived when percussive action for riveting, especially with steel rivets, had been practically abandoned. Many years ago, when Bessemer steel was originally introduced, he believed he had been the first to recommend the abandonment of percussive action in working the ingots. It was at that time considered essential that the ingots should be hammered. But after exhaustive experiments at Mr. Fox's works at Stocksbridge the conclusion was arrived at that hammering was a mistake, causing injury to the steel. It had consequently been abandoned there, and he believed those works had been the first to roll rails direct without any hammering of the ingots at all. Carrying out to its legitimate conclusion M. Tresca's beautiful theory of the flow of solids, it appeared to him that a percussive action on rivets was a mistake.

Mr. W. FALCONER KING considered that, while the author had gone to work in a very good way, he had not allowed quite sufficient power for the machines shown in the drawings. This however was a mere matter of detail, which would no doubt be improved later on. The amount of magnetism that would be available appeared to him to be not enough for bringing the two plates close together before riveting.

Mr. Benjamin A. Dobson, Member of Council, asked whether under any circumstances there would be any danger to the workmen attending these machines from the current of electricity passing through them. Also what precautions were taken with the holding-on magnets for ensuring a sufficient amount of contact; and whether any slip had been experienced from the vibration of the machine under work. If the contact was all over the surface of the ends of the holding-on magnets, it was clear that there would be a considerable surface available for holding, and the holding power would then be very great; but as neither plates of steel nor plates of iron had their surfaces absolutely true, there could only be a small portion of the magnet in absolute contact, and in that case it appeared to him that the amount of holding power would be greatly reduced.

Mr. W. Ford Smith asked whether the drills used were twist drills, and whether they had been working at their full power when drilling $\frac{7}{8}$-inch holes in 69 seconds each, as mentioned in the paper (page 329). From many hundreds of experiments that he had made, he had found it possible to drill a hole 1 inch in diameter through iron plates 1 inch thick in 46 seconds, or little more than half the time given by the author. He had also found that 75 holes $\frac{1}{2}$ inch diameter and $2\frac{3}{4}$ inches deep could be drilled through iron made of hammered scrap with this same excessively heavy feed, before the twist drill required to be re-ground.

Mr. Sydney F. Walker was sure the feeling of electrical engineers in regard to the present paper was one of hearty congratulation to the author on the success he had achieved. All were looking forward to the electrical transmission and distribution of power generally; and he believed those who had studied the matter were agreed that what was wanted in order to compete with tools at present in existence was the introduction of appliances of the kind now described. Many of the machines and tools now used for engineering work were self-contained, like a pump; it was only necessary to bring steam to them, and they would work independently of any other connections. At present, so far as he

(Mr. Sydney F. Walker.)
knew, the tools described in the paper were the only self-contained electrical tools in existence; and he thought their advent marked a distinct epoch in the history of the electrical transmission of power. What had been done in past years, when the Gramme machine was first brought over to England, could hardly be taken as serviceable for present guidance, because much that had been thought impossible only two or three years ago had now become a practical success.

As to the question very properly raised by Mr. Riches, he had himself purposed asking the author whether any increase of power had been found to be necessary, after detaching the drilling or riveting machine from its first piece of work, for then attaching it to the second. If not, or if the increase of power necessary were practically not appreciable, it seemed quite evident that the plate could not have taken up much magnetism, or not sufficient to do any harm. It was well known that steel and iron, particularly the former, took up magnetism and kept it; but it took it up very slowly and with great difficulty. It was a difficult matter to get a good piece of hard steel to magnetise at all. In the construction of apparatus in which steel magnets were used, there was very great difficulty in getting steel of any kind to magnetise properly. The known laws with regard to the magnetising of iron seemed none of them to have any bearing upon steel, owing to the great difficulty of getting it to magnetise. Seeing therefore that ships were now being built of steel principally, he considered there would not be sufficient magnetism left in the steel to affect the compasses or to affect the pitting in the boilers. As to the question of magnetising and de-magnetising the magnets for the holding-on arrangement, it was done every day for other purposes; and there was no difficulty in it if the electro-magnet was properly constructed, having sufficient iron put into it, and if it was properly insulated. It would be a very different matter if the magnetic circuit were completed.

It was stated in page 330 that the author had had no data for his guidance as to the holding power exerted by the magnets, and that such information as existed was applicable only to the conditions under which electro-magnets were used in dynamo machines. It might perhaps be of service to mention that from experiments made by himself the same general laws appeared to be equally true for magnets of all kinds, whether the largest magnets used in the most powerful dynamo machines, or the smallest magnets used for such light work as ringing the electric bells in colliery shafts. After the enunciation of the law of magnetic resistance by Mr. Kapp eighteen months ago, he had himself set to work on the colliery bells which he had previously been fitting up, to see whether the same law held true for them, and whether any saving could be effected in their construction; and he had found that the same general law did hold true exactly:—namely that the magnetic power, whether it were the holding-on power or whether it were the lines of force in the armature of the dynamo machine, varied directly as the exciting power, and inversely as the magnetic resistance; and that the magnetic resistance varied directly as the length of the magnetic circuit, and inversely as the area of its cross section. Practically the result at which he had arrived was that, in magnets of the construction shown in the drawings, which were similar to the little magnets used for working colliery bells, the magnets themselves could be very much shortened, and could be made of increased sectional area, to the extent of about three times the area at present adopted. The cost of manufacture was then less, and a considerably better pull was the result.

He enquired what dynamo had been used as a generator for working these machines; and whether there was any difficulty in handling the tools. Also whether there was any difference in the power required for working one of the caulking and chipping tools by an electro-motor, as shown in Figs. 10 and 11, Plate 59, and another by a solenoid, as in Fig. 12. A solenoid was known to be a very wasteful appliance, not giving out anything like the power that was put into it; but on the other hand it had the advantage of acting direct, whereas the motor acted through gearing. Had the author made any experiments showing which was the most economical?

Mr. ROWAN said that as to the cost of the machines he could only at present give approximate figures. The riveting or drilling machines represented in Figs. 1 and 6, Plates 56 and 57, would cost

(Mr. Rowan.)

roughly about £100 each. Their size was small, as their power was only about $\frac{1}{2}$ HP.; although the motor was capable of exerting from $\frac{3}{4}$ to 1 horse-power of actual work. A dynamo machine of about 4 HP. for working three or four machines could be got for about £60. For an installation comprising a large number of machines, say as many as twenty-five, which would be capable of completing the whole of the rivet holes in a large ship of 300 or 400 feet length in about thirty days, the whole of the machines including the dynamo and cable would cost about £3000. The same appliances would of course be available for the work of constructing a large number of ships. The first cost seemed something considerable; but against that, the reduction in thickness of plating which would probably be allowed, in consequence of the increased strength due to the absence of deterioration by punching, would amount to a considerable sum in each ship. Labour charges would be about the same as at present.

As to riveting, all that he could gather in the way of comparison between the work done by these machines and that done by other machines and in boiler works showed that the work was done in about the same time. The closing of a rivet took about eight seconds in the very best boiler work with hydraulic machines; and in ordinary work with the electro-magnetic riveter the same rivets had repeatedly been closed in from eight to ten seconds.

The cost of the motive power was difficult to arrive at, because it was simply a question of taking so much power from the engine to drive the dynamo; or, where the power was not available in that way, of supplying the necessary steam-power.

The influence of magnetism on ships was really very much a matter of imagination. It was easily understood that the magnetism produced by the attachment of these machines embraced only a small area; and in working over a ship's side or a boiler shell the magnetism was continually reversed and practically destroyed by the north pole of the holding-on magnet succeeding to the position occupied just previously by the south pole, or *vice versâ*. The amount of residual magnetism found in the side of a steel ship was therefore extremely small. Instead of the ship being turned into one huge magnet, there were so many poles mixed up all over the plates that the compasses could not be in any way affected even if the plates were permanently magnetised, which was very unlikely not only on account of the facts stated by Mr. Walker, but also because, although the material used in ship and boiler construction was popularly called steel, it was well known to be simply a fine quality of iron, very unlike tool steel. The probable effect on steel boilers of magnetism induced in the plates by the use of these machines had been spoken of by Mr. Riches; but in ascribing to them in this way the power of increasing the action of corrosion in boilers, it was evident that magnetism had been confounded with galvanic action, which latter was sometimes a cause of corrosion and had been proposed as a preventive in certain cases. Magnetism exerted on water no action of a chemical nature, such as galvanism or a galvanic current was capable of producing; and therefore, even if the plates should retain some permanent magnetism, this could not act in setting up any galvanic action, or in increasing the energy of corrosive agencies which might be present in a boiler.

Reference had been made by Mr. Sterne to the American plan of an electro-magnetic chuck, which was a simple method of applying magnetism to a lathe-chuck or planing-machine bed by making one portion of the chuck to form one pole of the magnet and the other portion the opposite pole. But in that case the holding power of the magnet was used in the very worst way in which it could be applied, namely to hold the work against force tending to produce a sliding movement; and he had found a magnet was of no use at all for such a purpose. With the machines described in the paper the magnets were used principally to hold against force acting directly against their pull; and it had been found that there was very little slipping down the side of the ship or the boiler, due to the weight of the machine, the tendency to slipping being easily overcome with sufficient magnetism. In working on any such structure as a ship's side, the tools had necessarily to be suspended by some slight slinging arrangement, just like the drilling machine now exhibited hanging from a support overhead, so as to guard against all possible risk of danger to the men working underneath; and any slip due to the weight of the machine, which weight would

(Mr. Rowan.)
really be a mere trifle in comparison with the holding power of the magnets, would be taken up in that way, even though the machine were ten times heavier than it was.

There was no danger at all in working with the ordinary electric currents, which of course could be made use of in machine work of that sort. The same current which was used in many establishments for electric lighting was quite applicable to working the electro-magnetic tools. It was well known that continuous currents of up to 150 volts potential were quite harmless. He had repeatedly seen the men take the whole of the current through their bodies without the slightest inconvenience, except a little tingling of the joints and muscles, which taught them rather to respect the machines than to be afraid of them.

The stroke of the hammer in the electro-magnetic riveter that had been made was $5\frac{1}{2}$ to 6 inches; and he had not found any bad results on the rivets themselves from the percussive action. The question of dealing with ingots was rather a different matter. Mr. Price-Williams had spoken of the evil effect which he had found from hammering Bessemer ingots; but it was well known that steel when first cast was in a very different state physically from that which it afterwards acquired in the course of being worked.

In the electro-magnetic drilling machine he had commenced with twist drills; but these were thought to be too expensive for ordinary ship-building work, and consequently only ordinary drills had been used in the ship-yard, namely flat drills with a cutting angle formed more or less acute according to the speed at which the work was being done. The holes spoken of in the paper as $\frac{7}{8}$ inch diameter (page 329) were $1\frac{1}{8}$ inch deep, and the time stated included what was required to move the machine from hole to hole; so that the speed of drilling them was very much the same as had been mentioned by Mr. Ford Smith.

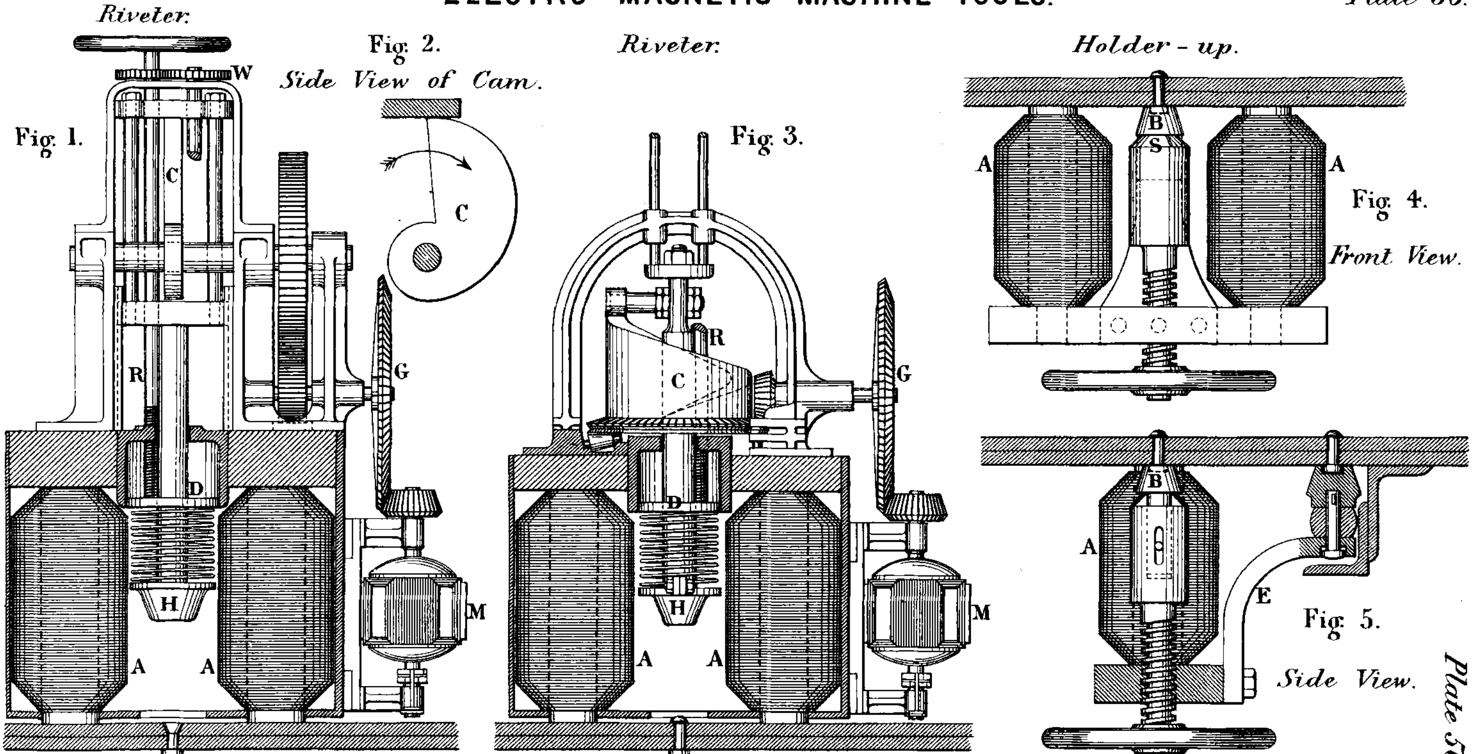
The shavings or cuttings, which had proved so troublesome in Mr. Sterne's trials, had not been found to occasion the slightest difficulty in the electro-magnetic drilling machine. The whole of the framework of the machine above the yoke joining the two magnet cores was made of brass or phosphor-bronze, so that the magnetism was not conducted away through the frame-work, but was confined to the wrought-iron yoke and the magnets, between which the magnetic circuit was completed through the plates. The drill-holder worked through this insulated framing. It was consequently found that, although the drill itself was slightly magnetised by induction from the plate, the magnetism in the poles of the magnets was so much stronger than any induced magnetism in the drill that the shavings actually flew out of the hole as though they were being blown out, and clustered themselves upon the magnets. The effect was positively to clear the hole, and thereby to render the lubrication of the cutting tool much easier. When the drill was between the magnet poles, as in Fig. 6, Plate 57, the cuttings flew out on opposite sides to both magnets alike; and when the drill projected beyond the magnets, as in Fig. 7, the effect was still the same in clearing the hole, although there was only one pole of the magnet near enough to attract the shavings.

The question of the comparative efficiency of solenoids he had not yet gone into. In reply to the enquiry about dynamos, any good dynamo machine was suitable for working the machines. In one case a shunt-wound dynamo of Messrs. Immisch's construction had been used; and in another case one of the Phœnix series-wound machines used for lighting had been employed.

The surmise (page 338) about the magnetism in the riveter and holder-up being insufficient to draw the plates together was not correct. As illustrating the extent to which the magnets affected each other through the plates, he had found that, when the electrical connections were incorrectly made, so that poles of like denominations faced each other on opposite sides of plating of $1\frac{1}{8}$ inch thickness, neither magnet held with sufficient strength to do the work, that is to say both magnets were weakened by induction. This proved the existence of considerable inductive effect, in addition to the holding-on power, which when properly directed must draw the magnets and the intervening plates together. He had not however measured the extent of this action with magnets of the size shown; and it would of course be governed by the proportionate mass of the plates forming a keeper to the magnets.

The PRESIDENT invited the Members to pass a hearty vote of thanks to Mr. Rowan for his excellent practical paper. No doubt if he succeeded in persuading shipbuilders to drill holes instead of punching them, it would add materially to the strength of ships; the holes would be correctly opposite one another, and the rivets would then be put in so as to fill them perfectly.

ELECTRO-MAGNETIC MACHINE-TOOLS.



(Proceedings Inst. M. E. 1887.) *Scale 1/10th* 0 10 20 30 40 Ins.

ELECTRO-MAGNETIC MACHINE-TOOLS.

Fig. 6. *Drilling Machine with drill between magnets.*

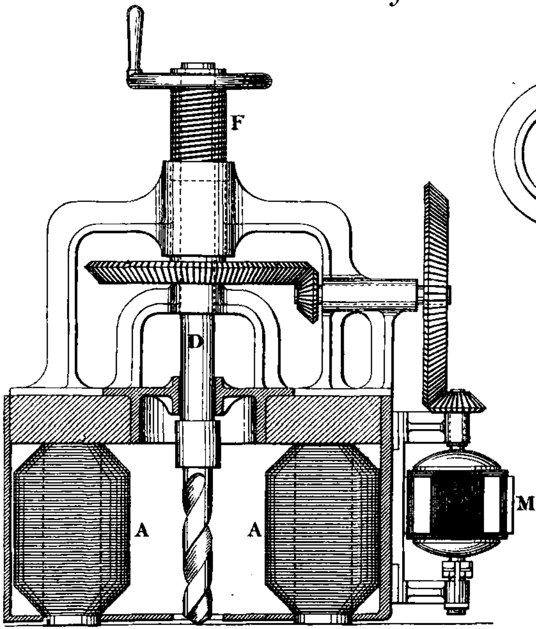
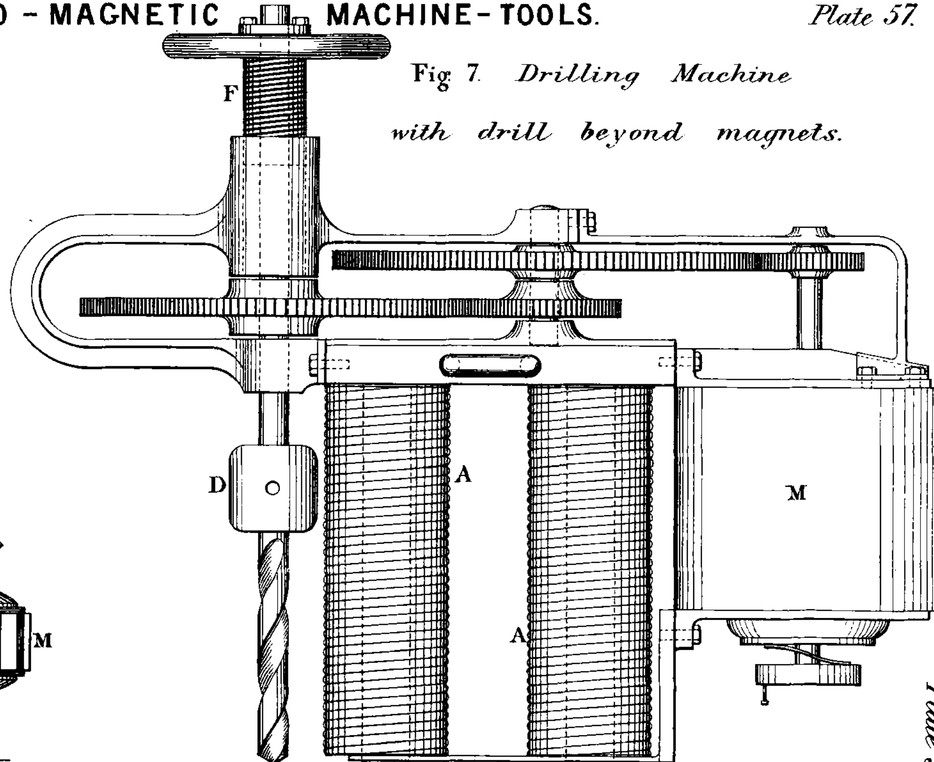


Fig. 7. *Drilling Machine with drill beyond magnets.*



(Proceedings Inst. M. E. 1887.) *Scale 1/10th.*

Inches. 0 10 20 30 40

Plate 57.

ELECTRO - MAGNETIC MACHINE - TOOLS.

Fig. 8. *Drilling Machine worked by hydraulic motor.*

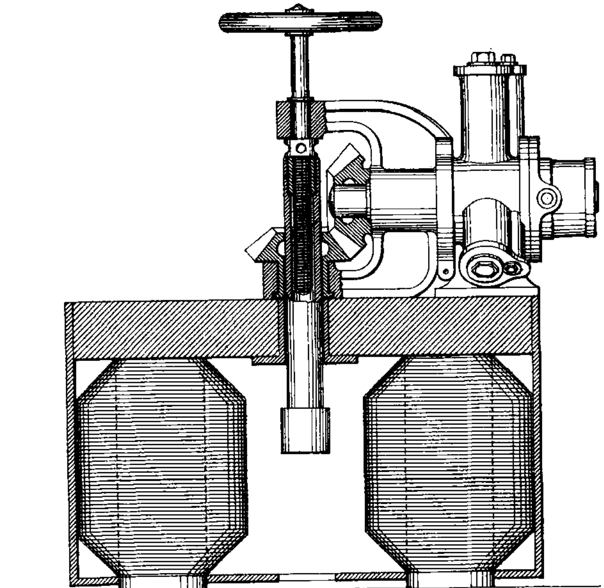
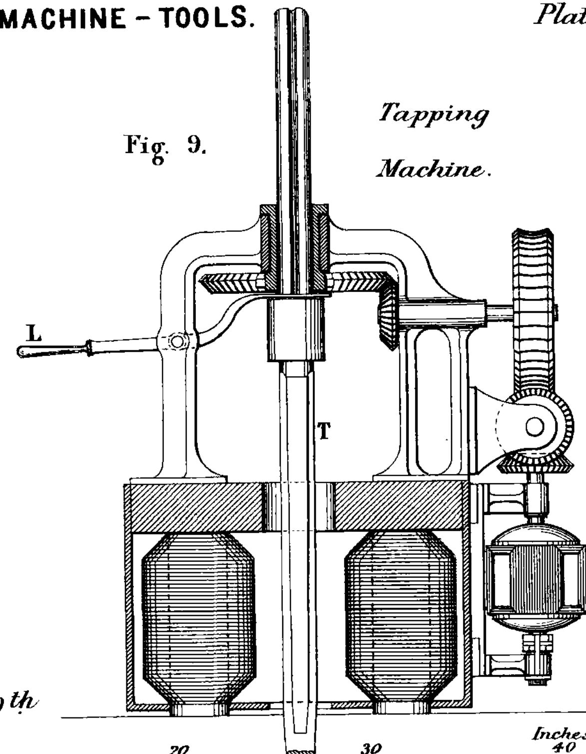


Fig. 9. *Tapping Machine.*



Scale 1/10th

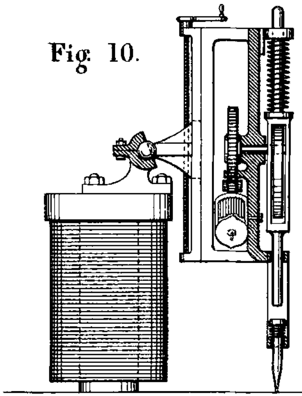
0 10 20 30 40 *Inches.*

Plate 58.

ELECTRO-MAGNETIC MACHINE-TOOLS.

Caulking and Chipping Machines.

Fig. 10.



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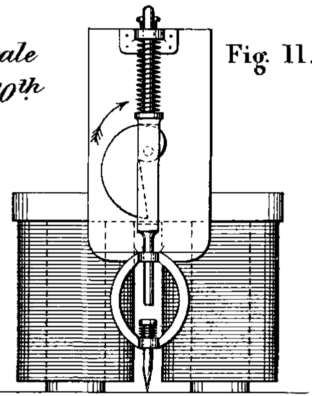
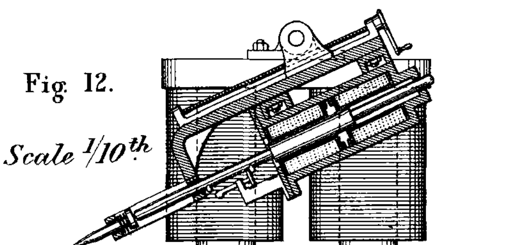


Fig. 11.

Fig. 12.

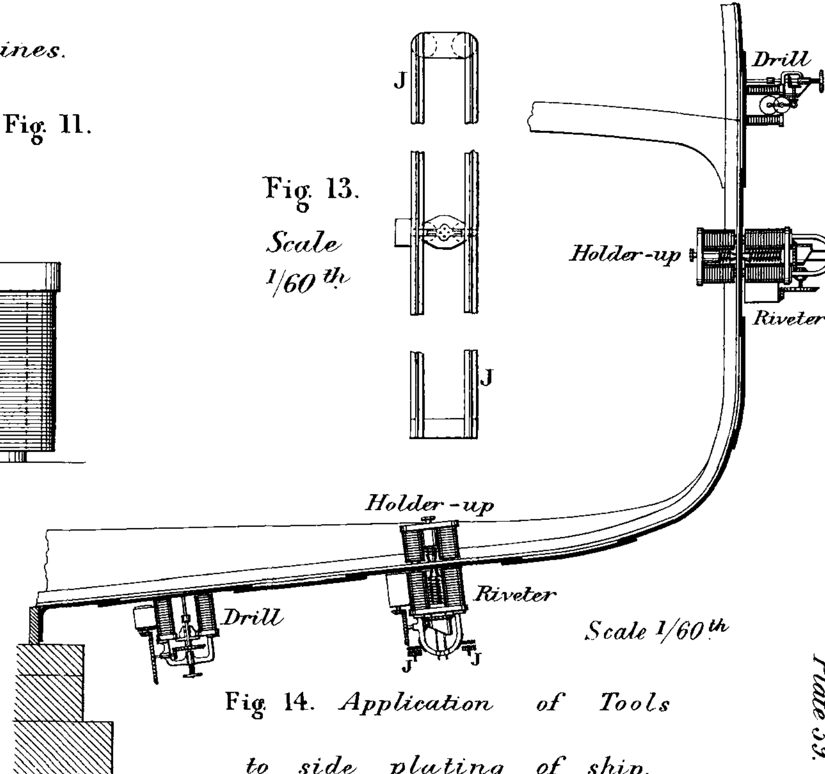
Scale 1/10th.



0 5 10 15 20 Inches.

Fig. 13.

Scale 1/60th.



Scale 1/60th.

Fig. 14. *Application of Tools to side plating of ship.*

(Proceedings Inst. M. E. 1887.)

Plate 59.

ELECTRO-MAGNETIC MACHINE-TOOLS.

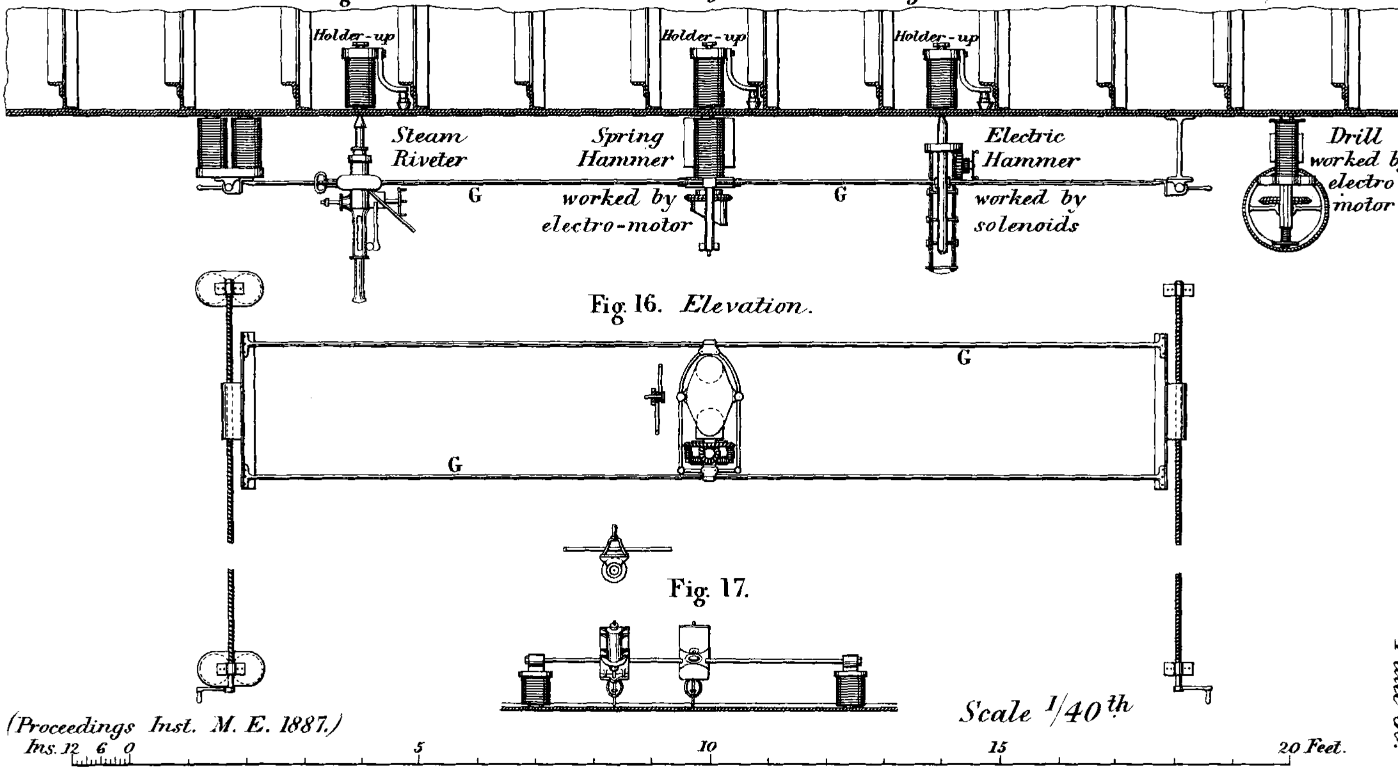
Plate 60.

Fig. 15. *Plan of Tools working on same guide-bar.* Scale 1/40th

Fig. 16. *Elevation.*

Fig. 17.

Scale 1/40th



(Proceedings Inst. M. E. 1887.)

Plate 60.