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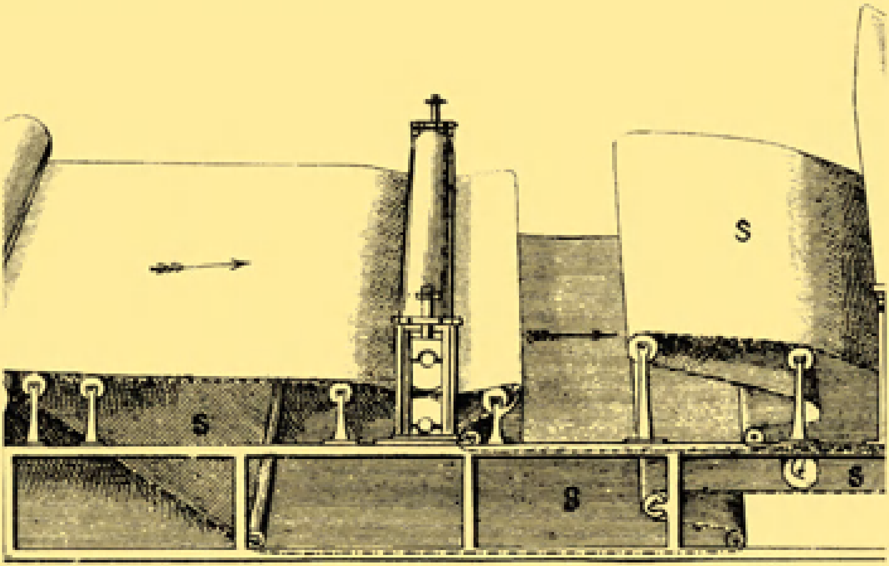
ON THE ECONOMY OF MACHINERY AND MANUFACTURES

Charles Babbage



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On the Economy of Machinery and Manufactures

In this famous book, first published in 1832, Charles Babbage (1791–1871), the mathematician, philosopher, engineer and inventor who originated the concept of a programmable computer, surveys manufacturing practices and discusses the political, moral and economic factors affecting them. The book met with hostility from the publishing industry on account of Babbage's analysis of the manufacture and sale of books. Babbage describes the many different printing processes of the time, analyses the costs of book production and explains the publication process, before discussing the 'too large' profit margins of booksellers. Babbage succeeded in his aim 'to avoid all technical terms, and to describe in concise language', making this an eminently readable historical account. His analysis and promotion of mechanisation and efficient 'division of labour' (still known as the 'Babbage principle') continue to resonate strongly for modern industrial engineering.

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On the Economy of Machinery and Manufactures

Charles Babbage

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On the

ECONOMY OF MACHINERY

AND

MANUFACTURES

By

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LONDON:
CHARLES KNIGHT, PALL MALL EAST.
1832.

TO

The University of Cambridge

THIS VOLUME

IS INSCRIBED

AS A TRIBUTE OF RESPECT

AND GRATITUDE

BY

THE AUTHOR.

PREFACE.

THE present volume may be considered as one of the consequences that have resulted from the Calculating-Engine, the construction of which I have been so long superintending. Having been induced during the last ten years to visit a considerable number of workshops and factories, both in England and on the Continent, for the purpose of endeavouring to make myself acquainted with the various resources of mechanical art, I was insensibly led to apply to them those principles of generalization to which my other pursuits had naturally given rise. The increased number of curious processes and interesting facts which thus came under my attention, as well as of the reflections which they suggested, induced me to believe that the publication of some of them might be of use to persons who propose to bestow their attention on those inquiries which I have only incidentally considered. With this view it was my intention to have delivered the present work in the form of a course of lectures at Cambridge; an intention which I was subsequently induced to alter. The substance of a considerable portion of it has, however, appeared among the preliminary chapters of the mechanical part of the Encyclopædia Metropolitana.

I have not attempted to offer a complete enumeration of all the mechanical principles which regulate the application of machinery to arts and manufactures, but I have endeavoured to present to the reader those which struck me as the most important, either for understanding the actions of machines, or for enabling the memory to classify and arrange the facts connected with their employment. Still less have I attempted to examine all the difficult questions of *political economy* which are intimately connected with such inquiries. It was impossible not to trace or to imagine, among the wide variety of facts presented to me, some principles which seemed to pervade many establishments; and having formed such conjectures, the desire to refute or to verify them gave an additional interest to the pursuit. Several of the principles which I have proposed, appeared to me to have been unnoticed before. This was particularly the case with respect to the explanation I have given of the *division of labour;* but further inquiry satisfied me that I had been anticipated by M. Gioja, and it is probable that additional research would enable me to trace most of the other principles, which I had thought original, to previous writers, to whose merit I may perhaps be unjust from my want of acquaintance with the historical branch of the subject.

The truth however of the principles I have stated, is of much more importance than their origin; and the utility of an inquiry into them, and of establishing others more correct, if these should be erroneous, can scarcely admit of a doubt.

The difficulty of understanding the processes of manufactures has unfortunately been greatly overrated. To examine them with the eye of a manufacturer, so as to be able to direct others to repeat them, does undoubtedly require much skill and previous acquaintance with the subject; but merely to apprehend their general principles and mutual relations, is within the power of almost every person possessing a tolerable education.

Those who possess rank in a manufacturing country can scarcely be excused if they are entirely ignorant of principles whose development has produced its greatness. The possessors of wealth can scarcely be indifferent to processes which nearly or remotely have been the fertile source of their possessions. Those who enjoy leisure can scarcely find a more interesting and instructive pursuit than the examination of the workshops of their own country, which contain within them a rich mine of knowledge, too generally neglected by the wealthier classes.

It has been my endeavour, as much as possible, to avoid all technical terms, and to describe in concise language the arts I have had occasion to discuss. In touching on the more abstract principles of political economy, after shortly stating the reasons on which they are founded, I have endeavoured to support them by facts and anecdotes; so that whilst young persons might be amused and instructed by the illustrations, those of more advanced judgment may find subject for meditation in the general conclusions to which they point. I was anxious to support the principles which I have advocated by the observations of others, and in this respect I found myself peculiarly fortunate. The Reports of Committees of the House of Commons upon various branches of commerce and manufactures, and the evidence which they have at different periods published on those subjects, teem with information of the most important kind, rendered doubly valuable by the circumstances under which it has been collected. From these sources I have freely taken, and I have derived some additional confidence from the support they have afforded to my views.*

CHARLES BABBAGE.

DORSET STREET, MANCHESTER SQUARE.
June 8, 1832.

* I am happy to avail myself of this occasion of expressing my obligations to the Right Hon. Manners Sutton, the Speaker of the House of Commons, to whom I am indebted for copies of a considerable collection of those reports.

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ON THE ECONOMY

OF

MANUFACTURES.

INTRODUCTION.

THE object of the present volume is to point out the effects and the advantages which arise from the use of tools and machines;—to endeavour to classify their modes of action;—and to trace both the causes and the consequences of applying machinery to supersede the skill and power of the human arm.

A view of the mechanical part of the subject will, in the first instance, occupy our attention, and to this the first section of the work will be devoted. The first chapter of the section will contain some remarks on the general sources from whence the advantages of machinery are derived, and the succeeding nine chapters will contain a detailed examination of principles of a less general character. The eleventh chapter contains numerous subdivisions, and is important from the extensive classification it affords of the arts in which copying is so largely employed The twelfth chapter, which completes the first section, contains a few suggestions for the assistance of those who propose visiting manufactories.

The second section, after an introductory chapter on the difference between *making* and *manufacturing*, will contain, in the succeeding chapters, a discussion of many of the questions which relate to the political economy of the subject. It was found that the domestic arrangement, or interior economy of factories, was so interwoven with the more general questions, that it was deemed unadvisable to separate the two subjects. The concluding chapter of this section, and of the work itself, relates to the future prospects of manufactures, as arising from the application of science.

CHAP. I.

SOURCES OF THE ADVANTAGES ARISING FROM MACHINERY AND MANUFACTURES.

(1.) THERE exists, perhaps, no single circumstance which distinguishes our country more remarkably from all others, than the vast extent and perfection to which we have carried the contrivance of tools and machines for forming those conveniences, of which so large a quantity is consumed by almost every class of the community. The amount of patient thought, of repeated experiment, of happy exertion of genius, by which our manufactures have been created and carried to their present excellence, is scarcely to be imagined. If we look around the rooms we inhabit, or through those storehouses of every convenience, of every luxury that man can desire, which deck the crowded streets of our larger cities, we shall find in the history of each article, of every fabric, a series of failures which have gradually led the way to excellence; and we shall notice, in the art of making even the most insignificant of them, processes calculated to excite our admiration by their simplicity, or to rivet our attention by their unlooked-for results.

(2.) The accumulation of skill and science which has been directed to diminish the difficulty of producing manufactured goods, has not been beneficial to that country alone in which it is concentrated; distant kingdoms have participated in its advantages. The luxurious natives of the East,* and the ruder inhabitants of the African desert, are alike indebted to our looms. The produce of our factories has preceded even our most enterprising travellers.† The cotton of India is conveyed by British ships round half our planet, to be woven by British skill in the factories of Lancashire: it is again set in motion by British capital; and, transported to the very plains whereon it grew, is repurchased by the lords of the soil which gave it birth, at a cheaper price than that at which their coarser machinery enables them to manufacture it themselves.‡

(3.) The large proportion of the population of this country, who are engaged in manufactures, appears from the following table deduced from a statement in an Essay on the Distribution of Wealth, by the Rev. R. Jones.—

* "The Bandana handkerchiefs manufactured at Glasgow "have long superseded the genuine ones, and are now con-"sumed in large quantities both by the natives and Chinese." —Crawfurd's *Indian Archipelago*, vol. iii. p. 505.

† Captain Clapperton, when on a visit at the court of the Sultan Bello, states, that "provisions were regularly sent me from "the sultan's table on pewter dishes with the London stamp: "and I even had a piece of meat served up on a white wash-"hand basin of English manufacture."—Clapperton's *Journey*, p. 88.

‡ At Calicut, in the East Indies (whence the cotton cloth called calico derives its name), the price of labour is *one-seventh* of that in England, yet the market is supplied from British looms.

For every Hundred Persons employed in Agriculture, there are,

	Agriculturists.	Non-agriculturists.
In Italy	100	31
In France	100	50
In England	100	200

The fact that the proportion of non-agricultural to agricultural persons is continually increasing, appears both from the Report of the Committee of the House of Commons upon Manufacturers' Employment, July, 1830, and also from the still later evidence of the last census, from which document the annexed table of the increase of population in our great manufacturing towns, has been deduced.

INCREASE OF POPULATION PER CENT.

Names of Places.	1801 to 1811.	1811 to 1821.	1821 to 1831.	Total 1801 to 1831.
Manchester	22	40	47	151
Glasgow	30	46	38	161
Liverpool *	26	31	44	138
Nottingham	19	18	25	75
Birmingham	16	24	33	90

Thus, in three periods of ten years each, during each of which the general population of the country

* Liverpool, though not itself a manufacturing town, has been placed in this list, from its great connexion with Manchester, of which it is the port.

has increased about 15 per cent., or nearly 51 per cent. upon the whole period of thirty years, the population of these towns has, on the average, increased 123 per cent. After this statement, the vast importance to the well-being of this country, of making the interests of its manufacturers well understood and attended to, needs no further argument.

(4.) The advantages which are derived from machinery and manufactures seem to arise principally from three sources : *The addition which they make to human power.—The economy they produce of human time.—The conversion of substances apparently common and worthless into valuable products.*

(5.) *Of additions to human power.* With respect to the first of these causes, the forces derived from wind, from water, and from steam, present themselves to the mind of every one; these are, in fact, additions to human power, and will be considered in a future page : there are, however, other sources of its increase, by which the animal force of the individual is itself made to act with far greater than its unassisted power; and to these we shall at present confine our observations. The construction of palaces, of temples, and of tombs, seems to have occupied the earliest attention of nations just entering on the career of civilization ; and the enormous blocks of stone moved from their native repositories to minister to the grandeur or piety of the builders, have remained to excite the astonishment of their posterity, long after the purposes of many of these records, as well as the names of their founders, have been forgotten. The different degrees of force necessary to move these ponderous masses, will have varied according to the mechanical knowledge of the people employed in their transport; and that the extent of power required for this purpose is widely different under different circumstances, will appear from the following experiment, which is related by M. Redelet, *Sur L'Art de Bâtir.*

A block of squared stone was taken for the subject of experiment;

	lbs.
1. Weight of stone	1080
2. In order to drag this stone along the floor of the quarry, roughly chiselled, it required a force equal to	758
3. The same stone dragged over a floor of planks required	652
4. The same stone placed on a platform of wood, and dragged over a floor of planks, required	606
5. After soaping the two surfaces of wood which slid over each other, it required .	182
6. The same stone was now placed upon rollers of three inches diameter, when it required to put it in motion along the floor of the quarry	34
7. To drag it by these rollers over a wooden floor	28
8. When the stone was mounted on a wooden platform, and the same rollers placed between that and a plank floor, it required	22

From this experiment it results, that the force necessary to move a stone along the roughly chiselled floor of its quarry is nearly two-thirds of its weight; to move it along a wooden floor, three-fifths; by wood upon wood, five-ninths; if the wooden surfaces are soaped, one-sixth; if rollers are used on the floor of the quarry, it requires one thirty-second part of the weight; if they roll over wood, one-fortieth; and if they roll between wood, one-fiftieth of its weight. At each increase of knowledge, as well as on the contrivance of every new tool, human labour becomes abridged. The man who contrived rollers, invented a tool by which his power was quintupled. The workman who first suggested the employment of soap, or grease, was immediately enabled to move, without exerting a greater effort, more than three times the weight he could before.*

(6.) *The economy of human time* is the next advantage of machinery in manufactures. So extensive and important is this effect, that we might, if we were inclined to generalize, embrace almost all the advantages under this single head; but the elucidation of principles of less extent will contribute more readily to a knowledge of the subject; and, as numerous examples will be presented to the reader in the ensuing pages, we shall restrict our illustrations upon this point.

As an example of the economy of time, the use of gunpowder in blasting rocks may be noticed. Several pounds of that substance may be purchased for a sum acquired by a few days' labour; yet when this is employed for the purpose alluded to, effects are frequently produced which could not, even with the

* So sensible are the effects of grease in diminishing friction, that the drivers of sledges in Amsterdam, on which heavy goods are transported, carry in their hand a rope soaked in tallow, which they throw down from time to time before the sledge, in order that it may by passing over the rope become greased.

best tools, be accomplished by other means in less than many months.

(7.) The art of using the diamond for cutting glass has undergone, within a few years, a very important improvement. A glazier's apprentice, when using a diamond set in a conical ferrule, as was always the practice about twenty years since, found great difficulty in acquiring the art of using it with certainty, and at the end of a seven years' apprenticeship many were found but indifferently skilled in its employment. This arose from the difficulty of finding the precise angle at which the diamond cuts, and of guiding it along the glass at the proper inclination when that angle is found. Almost the whole of the time consumed and of the glass destroyed in acquiring the art of cutting glass, may now be saved by the use of an improved tool. The gem is set in a small piece of squared brass with its edge nearly parallel to one side of the square. A person skilled in its use now files away one side of the brass, until, by trial, he finds that the diamond will make a clean cut, when guided by keeping this edge pressed against a ruler. The diamond and its mounting are now attached to a stick similar to a pencil, by means of a swivel allowing a small angular motion. Thus the merest tyro at once applies the cutting edge at the proper angle, by pressing the side of the brass against a ruler; and even though the part he holds in his hand should deviate a little from the required angle, it communicates no irregularity to the position of the diamond, which rarely fails to do its office when thus employed.

The relative hardness of the diamond, in different directions, is a singular fact. An experienced workman, on whose judgment I can rely, informed me that he had seen a diamond ground with diamond powder on a cast-iron mill for three hours without its being at all worn, but that, changing its direction with reference to the grinding surface, the same edge was ground down.

(8.) *Employment of materials of little value.* The skins used by the goldbeater are produced from the offal of animals. The hoofs of horses and cattle, and other horny refuse, are employed in the production of the prussiate of potash, that beautiful, yellow, crystallized salt, which is exhibited in the shops of some of our chemists. The worn-out saucepans and tin ware of our kitchens, when beyond the reach of the tinker's art, are not utterly worthless. We sometimes meet carts loaded with old tin kettles and worn-out iron coal-scuttles traversing our streets. These have not yet completed their useful course; the less corroded parts are cut into strips, punched with small holes, and varnished with a coarse black varnish for the use of the trunk-maker, who protects the edges and angles of his boxes with them; the remainder are conveyed to the manufacturing chemists in the outskirts of the town, who employ them, in conjunction with pyroligneous acid, in making a black die for the use of calico printers.

(9.) *Of tools.* The difference between a *tool* and a *machine* is not capable of very precise distinction; nor is it necessary, in a popular explanation of those terms, to limit very strictly their acceptation. A *tool* is usually more *simple* than a machine; it is generally used with the hand, whilst a machine is frequently moved by animal or steam power. The simpler *machines* are often merely one or more *tools* placed in a frame, and acted on by any moving power. In pointing out the advantages of *tools*, we shall commence with some of the simplest.

(10.) To arrange twenty thousand needles thrown promiscuously into a box, mixed and entangled with each other in every possible direction, in such a form that they shall be all parallel to each other, would, at first sight, appear a most tedious occupation; in fact, if each needle were to be separated individually, many hours must be consumed in the process. Yet this is an operation which must be performed many times in the manufacture of needles; and it is accomplished in a few minutes by a very simple *tool;* nothing more being requisite than a small flat tray of sheet iron, slightly concave at the bottom. The needles are placed in it and shaken in a peculiar manner, by throwing them up a very little, and giving at the same time a slight longitudinal motion to the tray. The shape of the needles assists their arrangement; for if two needles cross each other, (unless, which is exceedingly improbable, they happen to be precisely balanced,) they will, when they fall on the bottom of the tray, tend to place themselves side by side, and the hollow form of the tray assists this disposition. As they have no projection in any part to impede this tendency, or to entangle each other, they are, by continually shaking, arranged lengthwise, in three or four minutes. The direction of the shake is now changed, the needles are but little thrown up, but the tray is shaken endways; the result of which is, that in a minute or two the needles which were previously arranged endways become heaped up in a wall, with their ends against the extremity of the tray. They are now removed by hundreds at a time, by raising them with a broad iron spatula, on which they are retained by the fore-finger of the left hand. During the progress of the needles towards their finished state, this parallel arrangement must be repeated many times; and unless a cheap and expeditious method had been devised, the expense of manufacturing needles would have been considerably enhanced.

(11.) Another process in the art of making needles furnishes an example of one of the simplest contrivances which can come under the denomination of a *tool*. After the needles have been arranged in the manner just described, it is necessary to separate them into two parcels, in order that their points may be all in one direction. This is usually done by women and children. The needles are placed sideways in a heap, on a table, in front of each operator, just as they are arranged by the process above described. From five to ten are rolled towards this person by the forefinger of the left hand; this separates them a very small space from each other, and each in its turn is pushed lengthwise to the right or to the left, according as its eye is on the right or the left hand. This is the usual process, and in it every needle passes individually under the finger of the operator. A small alteration expedites the process considerably: the child puts on the forefinger of its right hand a small cloth cap or finger-stall, and rolling out of the heap from six to twelve needles, he keeps them down by the forefinger of the left hand, whilst he presses the forefinger of the right hand gently against their ends: those which have the points towards the right hand stick into the finger-stall; and the child, removing the finger of the left hand, slightly raises the needles sticking into the cloth, and then pushes them towards the left side. Those needles which had their eyes on the right hand do not stick into the finger cover, and are pushed to the heap on the right side previously to the repetition of this process. By means of this simple contrivance each movement of the finger, from one side to the other, carries five or six needles to their proper heap; whereas, in the former method, frequently only one was moved, and rarely more than two or three were transported at one movement to their place.

(12.) Various operations occur in the arts in which the assistance of an additional hand would be a great convenience to the workman, and in these cases tools or machines of the simplest structure come to our aid: vices of different forms, in which the material to be wrought is firmly grasped by screws, are of this kind, and are used in almost every workshop; but a more striking example may be found in the trade of the nail-maker.

Some kinds of nails, such as those used for defending the soles of coarse shoes, called hobnails, require a particular form of the head, which is made by the stroke of a die. The workman holds the red-hot rod of iron out of which he forms them in his left hand; with his right hand he hammers the end of it into a point, and cutting the proper length almost off, bends it nearly at right angles. He puts this into a hole in a small stake-iron immediately under a hammer connected with a treadle, which has a die sunk in its surface corresponding to the intended form of the head; and having given one part of the form to the head by the small hammer in his hand, he moves the treadle with his foot, which disengages the other hammer, and completes the figure of the head; the returning stroke produced by the movement of the treadle striking the finished nail out of the hole in which it was retained. Without this substitution of his foot for another hand, the workman would, probably, be obliged to heat the nails twice over.

(13.) Another, although fortunately a less general substitution of tools for human hands, is used to assist the labour of those who are deprived by nature, or by accident, of some of their limbs. Those who have had an opportunity of examining the beautiful contrivances for the manufacture of shoes by machinery, which we owe to the fertile invention of Mr. Brunel, must have noticed many instances in which the workmen were enabled to execute their task with precision, although labouring under the disadvantages of the loss of an arm or a leg. A similar instance occurs at Liverpool, in the Institution for the Blind, where a machine is used by those afflicted with blindness, for weaving sash-lines; it is said to have been the invention of a person suffering under that calamity. Other instances might be mentioned of contrivances for the use, the amusement, or the instruction of the wealthier classes, who labour under the same natural disadvantages. These triumphs of skill and ingenuity deserve a double portion of our admiration when applied to mitigate the severity of natural or accidental misfortune;—when they supply the rich with occupation and knowledge;—when they relieve the poor from the additional evils of poverty and want.

(14.) *Division of the objects of machinery.* There exists a natural, although, in point of number, a very unequal division amongst machines: they may be classed as; 1*st. Those which are employed to produce power;* and as, 2*dly. Those which are intended merely to transmit force and execute work.* The first of these divisions is of great importance, and is very limited in the variety of its species, although some of those species consist of numerous individuals.

Of that class of mechanical agents by which motion is transmitted,—the lever, the pulley, the wedge, and many others,—it has been demonstrated, that no power is gained by their use, however combined. *Whatever force is applied at one point can only be exerted at some other, diminished by friction and other incidental causes;* and it has been further proved, that *whatever is gained in the rapidity of execution is compensated by the necessity of exerting additional force.* These two principles, long since placed beyond the reach of doubt, cannot be too constantly borne in mind. But in limiting our attempts to things which are possible, we are still, as we hope to shew, possessed of a field of inexhaustible research, and of advantages derived from mechanical skill, which have but just begun their influence on our arts, and may be pursued without limit,—contributing to the improvement, the wealth, and the happiness of our race.

(15.) Of those machines by which we produce power, it may be observed, that although they are to us immense acquisitions, yet in regard to two of the sources of this power,—the force of wind and of water,—we merely make use of bodies in a state of motion by nature; we change the directions of their movement in order to render them subservient to our purposes, but we neither add to nor diminish the quantity of motion in existence. When we expose the sails of a windmill obliquely to the gale, we check the velocity of a small portion of the atmosphere, and convert its own rectilinear motion into one of rotation in the sails; we thus change the direction of force, but we create no power. The same may be observed with regard to the sails of a vessel; the quantity of motion given by them is precisely the same as that which is destroyed in the atmosphere. If we avail ourselves of a descending stream to turn a water-wheel, we are appropriating a power which nature may appear, at first sight, to be uselessly and irrecoverably wasting, but which, upon due examination, we shall find she is ever repairing by other processes. The fluid which is falling from a higher to a lower level, carries with it the velocity due to its revolution with the earth at a greater distance from its centre. It will therefore accelerate, although to an almost infinitesimal extent, the earth's daily rotation. The sum of all these increments of velocity, arising from the descent of all the falling waters on the earth's surface, would in time become perceptible, did not nature, by the process of evaporation, convey the waters back to their sources; and thus again, by removing matter to a greater distance from the centre, destroy the velocity generated by its previous approach.

(16.) The force of vapour is another fertile source of moving power; but even in this case it cannot be maintained that power is created. Water is converted into elastic vapour by the combustion of fuel. The chemical changes which thus take place are constantly increasing the atmosphere by large quantities of carbonic acid and other gases noxious to animal life. The means by which nature decomposes or reconverts these elements into a solid form, are not sufficiently known: but if the end could be accomplished by mechanical force, it is almost certain that the power necessary to produce it would at least equal that which was generated by the original combustion. Man, therefore, does not create power; but, availing himself of his knowledge of nature's mysteries he applies his talents to diverting a small and limited portion of her energies to his own wants: and, whether he employs the regulated action of steam, or the more rapid and tremendous effects of gunpowder, he is only producing on a small scale compositions and decompositions which nature is incessantly at work in reversing, for the restoration of that equilibrium which we cannot doubt is constantly maintained throughout even the remotest limits of our system. The operations of man participate in the character of their author; they are diminutive, but energetic during the short period of their existence: whilst those of nature, acting over vast spaces, and unlimited by time, are ever pursuing their silent and resistless career.

(17.) In stating the broad principle, that all combinations of mechanical art can only augment the force communicated to the machine at the expense of the time employed in producing the effect, it might, perhaps, be imagined, that the assistance derived from such contrivances is small. This is, however, by no means the case: since the almost unlimited variety they afford, enables us to exert to the greatest advantage whatever force we employ. There is, it is true, a limit beyond which it is impossible to reduce the power necessary to produce any given effect, but it very seldom happens that the methods first employed at all approach that limit. In dividing the knotted root of a tree for the purposes of fuel, how very different will be the time consumed, according to the nature of the tool made use of! The hatchet, or the adze, will divide it into small parts, but will consume a large portion of the workman's time. The saw will answer the same purpose more effectually and more quickly. This, in its turn, is superseded by the wedge, which rends it in a still shorter time. If the circumstances are favourable, and the workman skilful, the time and expense may be still further reduced by the use of a small quantity of gunpowder exploded in holes judiciously placed in the block.

(18.) When a mass of matter is to be removed, a certain force must be expended; and upon the proper economy of this force the price of transport will depend. A country must, however, have reached a high degree of civilization before it will have approached the limit of this economy. The cotton of Java is conveyed in junks to the coast of China; but from the seed not being previously separated, three quarters of the weight thus carried is not cotton. This might, perhaps, be justified in Java by the want of machinery to separate the seed, or by the relative cost of the operation in the two countries. But the cotton itself, as packed by the Chinese, occupies three times the bulk of an equal quantity shipped by Europeans for their own markets. Thus the freight of a given quantity of cotton costs the Chinese nearly twelve times the price to which, by a proper attention to mechanical methods, it might be reduced.*

* Crawfurd's *Indian Archipelago.*

CHAP. II.

ACCUMULATING POWER.

(19.) WHENEVER the work to be done requires more force for its execution than can be generated in the time necessary for its completion, recourse must be had to some mechanical method of preserving and condensing a part of the power exerted previously to the commencement of the process. This is most frequently accomplished by a fly-wheel, which is in fact nothing more than a wheel having a very heavy rim, so that the greater part of its weight is near the circumference. It requires great power applied for some time to put this into rapid motion; but when moving with considerable velocity, the effects are exceedingly powerful if its force be concentrated upon a small object. In some of the iron works where the power of the steam-engine is a little too small for the rollers which it drives, it is usual to set the engine at work a short time before the red-hot iron is ready to be removed from the furnace to the rollers, and to allow it to work with great rapidity until the fly has acquired a velocity rather alarming to those unused to such establishments. On passing the softened mass of iron through the first groove, the engine receives a great and very perceptible check; and its speed is diminished at the next and at each succeeding passage, until the iron bar is reduced to such a size that the ordinary power of the engine is sufficient to roll it.

(20.) The powerful effect of a large fly-wheel when its force can be concentrated in a point, was curiously illustrated at one of the largest of our manufactories. The proprietor was shewing to a friend the method of punching holes in iron plates for the boilers of steam-engines. He held in his hand a piece of sheet-iron three-eighths of an inch thick, which he placed under the punch. Observing, after several holes had been made, that the punch made its perforations more and more slowly, he called to the engine-man to know what made the engine work so sluggishly, when it was found that the fly-wheel and punching apparatus had been detached from the steam-engine just at the commencement of his experiment.

(21.) Another mode of accumulating power arises from lifting a weight and then allowing it to fall. A man, even with a heavy hammer, might strike repeated blows upon the head of a pile without producing any effect. But if he raises a much heavier hammer to a much greater height, its fall, though far less frequently repeated, will produce the desired effect.

CHAP. III.

REGULATING POWER.

(22.) Uniformity and steadiness in the rate at which machinery works, are essential both for its effect and its duration. That beautiful contrivance the governor of the steam-engine, must immediately occur to all who are familiar with that admirable machine. Wherever the increased speed of an engine would lead to injurious or dangerous consequences, it is applied; and is equally the regulator of the water-wheel which drives a spinning-jenny, or of the wind-mills which drain our fens. In the dock-yard at Chatham, the descending motion of a large platform, on which timber is raised, is regulated by a governor; but as the weight is very considerable, the velocity of this governor is still further checked by causing its motion to take place in water.

The regularity of the supply of fuel to the fire under the boilers of steam-engines is another mode of contributing to the uniformity of their rate, and also economizes the consumption of coal. Several patents have been taken out for methods of regulating this supply: the general principle being to make the engine supply the fire by means of a hopper, with small quantities of fuel at regular intervals, and to diminish this supply when it works quickly. One of the incidental advantages of this plan is, that by throwing on a very small quantity of coal at a time, the smoke is almost entirely consumed. The dampers of ashpits and chimneys are also in some cases connected with machines in order to regulate their speed.

(23.) Another contrivance for regulating the effect of machinery consists in a vane or a fly, of little weight, but presenting a large surface. This revolves rapidly, and soon acquires a uniform rate, which it cannot greatly exceed, because any addition to its velocity produces a much greater addition to the resistance it meets with from the air. The interval between the strokes on the bell of a clock is regulated by this means ; and the fly is so contrived, that this interval may be altered by presenting the arms of it more or less obliquely to the direction in which they move. This kind of fly, or vane, is generally used in the smaller kinds of mechanism, and, unlike the heavy fly, it is a destroyer instead of a preserver of force. It is the regulator used in musical boxes, and in almost all mechanical toys.

(24.) Another very beautiful contrivance for regulating the number of strokes made by a steam-engine, is used in Cornwall: it is called the *cataract*, and depends on the time required to fill a vessel plunged in water, the opening of the valve through which the fluid is admitted being adjustable at the will of the engine man.

CHAP. IV.

INCREASE AND DIMINUTION OF VELOCITY.

(25.) THE fatigue produced on the muscles of the human frame does not altogether depend on the actual force employed in each effort, but partly on the frequency with which it is exerted. The exertion necessary to accomplish every operation consists of two parts: one of these is the expenditure of force which is necessary to drive the tool or instrument; and the other is the effort required for the motion of some limb of the animal producing the action. If we take as an example the act of driving a nail into a piece of wood, the first of these is, the *propelling* the hammer head against the nail; the other is, *raising* the arm in order to lift the hammer. If the weight of the hammer is considerable, the former part will cause the greatest portion of the exertion. If the hammer is light, the exertion of *raising* the arm will produce the greatest part of the fatigue. It does therefore happen, that operations requiring very trifling force, if frequently repeated, will tire more effectually than more laborious work. There is also a degree of rapidity beyond which the action of the muscles cannot be pressed.

(26.) The most advantageous load for a porter who carries wood up stairs on his shoulders, has been investigated by M. Coulomb; but he found from experiment that a man walking up stairs without any load, and raising his burden by means of his own weight in descending, could do as much work in one day, as four men employed in the ordinary way with the most favourable load.

(27.) The proportion between the velocity with which men or animals move, and the weights they carry, is a matter of considerable importance, particularly in military affairs. It is also of great importance for the economy of labour, to adjust the weight of that part of the animal's body which is moved, the weight of the tool it urges, and the frequency of repetition of these efforts, so as to produce the greatest effect. An instance of the saving of time by making the same motion of the arm execute two operations instead of one, occurs in the simple art of making the tags of boot-laces: they are formed out of very thin, tinned, sheet-iron, and were formerly cut out of long strips of that material into pieces of such a breadth that when bent round they just enclosed the lace. Two pieces of steel have recently been fixed to the side of the shears, by which each piece of tinned-iron as soon as it is cut is bent into a semi-cylindrical form. The additional power required for this operation is almost imperceptible; and it is executed by the same motion of the arm which produces the cut. The work is usually performed by women and children; and with the improved tool more than three times the quantity of tags is produced in a given time.*

Whenever the work is itself light, it becomes necessary, in order to economize time, to increase the

* See *Transactions of the Society of Arts*, 1826.

velocity. Twisting the fibres of wool by the fingers would be a most tedious operation : in the common spinning-wheel the velocity of the foot is moderate, but by a very simple contrivance that of the thread is most rapid. A piece of cat-gut passing round a large wheel, and then round a small spindle, effects this change. This contrivance is common to a multitude of machines, some of them very simple. In large shops for the retail of ribands, it is necessary at short intervals to " take stock," that is, to measure and re-wind every piece of riband, an operation which, even with this mode of shortening it, is sufficiently tiresome, but without it would be almost impossible from its expense. The small balls of sewing-cotton, so cheap and so beautifully wound, are formed by a machine on the same principle, and but a few steps more complicated.

(28.) In turning from the smaller instruments in frequent use to the larger and more important machines, the economy arising from the increase of velocity becomes more striking. In converting cast into wrought iron, a mass of metal of about a hundred weight is heated almost to a white heat, and placed under a heavy hammer moved by water or steam power. This is raised by a projection on a revolving axis ; and if the hammer derived its momentum only from the space through which it fell, it would require a considerably greater time to give a blow. But as it is important that the softened mass of red-hot iron should receive as many blows as possible before it cools, the form of the cam or projection on the axis is such, that, the hammer, instead of being lifted to a small height, is thrown up with a jerk, and almost the instant after it strikes against a large beam, which acts as a powerful spring, and drives it down on the iron with such velocity that by these means about double the number of strokes can be made in a given time. In the smaller tilt-hammers, this is carried still further: by striking the tail of the tilt-hammer forcibly against a small steel anvil, it rebounds with such velocity, that from three to five hundred strokes are made in a minute.

(29.) In the manufacture of scythes, the length of the blade renders it necessary that the workman should move readily, so as to bring every part on the anvil in quick succession. This is effected by placing him in a seat suspended by ropes from the ceiling: so that he is enabled, with little bodily exertion, by pressing his feet against the block which supports the anvil, to vary his distance to any required extent. In the manufacture of anchors, an art in which this contrivance is of still greater importance, it has only been recently applied.

(30.) The most frequent reason for employing contrivances for diminishing velocity, arises from the necessity of overcoming great resistances with small power. Systems of pulleys, the crane, and many other illustrations might also here be adduced; but they belong more appropriately to some of the other causes which we have assigned for the advantages of machinery. The common smoke-jack is an instrument in which the velocity communicated is too great for the purpose required, and it is transmitted through wheels which reduce it to a more moderate rate.

CHAP. V.

EXTENDING THE TIME OF ACTION OF FORCES.

(31.) This is one of the most common and most useful of the employments of machinery. The half minute which we daily devote to the winding up of our watches is an exertion of labour almost insensible; yet by the aid of a few wheels its effect is spread over the whole twenty-four hours. In our clocks this extension of the time of action of the original force impressed is carried still further; the better kind usually require winding up once in eight days, and some are occasionally made to continue in action during a month, or even a year. Another familiar illustration may be noticed in our domestic furniture: the common jack by which our meat is roasted, is a contrivance to enable the cook in a few minutes to exert a force which the machine retails out during the succeeding hour in turning the loaded spit; thus enabling her to bestow her undivided attention on the other important duties of her vocation. A great number of automatons and mechanical toys moved by springs, may be classed under this division.

(32.) A small moving power, in the shape of a jack or a spring with a train of wheels, is often of great convenience to the experimental philosopher, and has been used with advantage in magnetic and electric experiments where the rotation of a disk of metal or other body is necessary, thus allowing to the inquirer the unimpeded use of both his hands. A vane connected by a train of wheels, and set in motion by a heavy weight, has also on some occasions been employed in chemical processes, to keep a solution in a state of agitation. Another object to which a similar apparatus may be applied, is the polishing of small specimens of minerals for optical experiments.

CHAP. VI.

SAVING TIME IN NATURAL OPERATIONS.

(33.) The process of tanning will furnish us with a striking illustration of the power of machinery in accelerating certain processes in which natural operations have a principal effect. The object of this art is to combine a certain principle called *tanning* with every particle of the skin to be tanned. This in the ordinary process is accomplished by allowing the skins to soak in pits containing a solution of tanning matter: they remain in the pits six, twelve, or eighteen months; and in some instances, (if the hides are very thick,) they are exposed to the operation for two years, or even during a longer period. This length of time is apparently required in order to allow the tanning matter to penetrate into the interior of a thick hide. The improved process consists in placing the hides with the solution of tan in close vessels, and then exhausting the air. The consequence of this is to withdraw any air which might be contained in the pores of the hides, and to employ the pressure of the atmosphere to aid capillary attraction in forcing the tan into the interior of the skins. The effect of the additional force thus brought into action can be equal only to one atmosphere, but a further improvement has been made: the vessel containing the hides is, after exhaustion, filled up with a solution of tan; a small additional quantity is then injected with a forcing-pump. By these means any degree of pressure may be given which the containing vessel is capable of supporting; and it has been found that, by employing such a method, the thickest hides may be tanned in six weeks or two months.

(34.) The same process of injection might be applied to impregnate timber with tar, or any other substance adapted to preserve it from decay; and if it were not too expensive, the deal floors of houses might thus be impregnated with alumine or other substances, which would render them much less liable to be accidentally set on fire. Some idea of the quantity of matter which can be injected into wood, by great pressure, may be formed from considering the fact stated by Mr. Scoresby, respecting an accident which occurred to a boat of one of our whaling-ships. The line of the harpoon being fastened to it, the whale in this instance dived directly down, and carried the boat along with him. On returning to the surface the animal was killed, but the boat, instead of rising, was found suspended beneath the whale by the rope of the harpoon; and on drawing it up, every part of the wood was found to be so completely saturated with water as to sink immediately to the bottom.

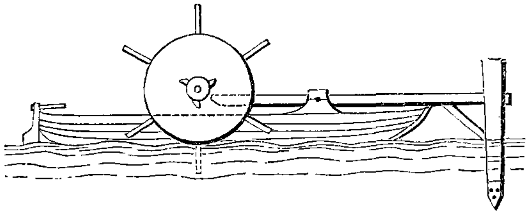
(35.) The operation of bleaching linen in the open air is one for which considerable time is necessary; and although it does not require much labour, yet, from the risk of damage and of robbery from long exposure, a mode of shortening the process was highly desirable. The method now practised, although not mechanical, is such a remarkable instance of the application of science to the practical purposes of manufactures, that in mentioning the advantages derived from shortening natural operations, it would have been scarcely pardonable to have omitted all allusion to the beautiful application of chlorine, in combination with lime, to the art of bleaching.

(36.) Another instance more strictly mechanical occurs in some countries where fuel is expensive, and the heat of the sun is not sufficient to evaporate the water from brine springs. The water is first pumped up to a reservoir, and then allowed to fall in small streams through fagots. Thus it becomes divided; and, presenting a large surface, evaporation is facilitated, and the brine which is collected in the vessels below the fagots is stronger than that which was pumped up. After thus getting rid of a large part of the water, the remaining portion is driven off by boiling. The success of this operation depends on the circumstance of the atmosphere not being saturated with moisture: if the air at the time the brine falls through the fagots holds in solution as much moisture as it can contain in an invisible state, none can be absorbed from the salt water, and the labour expended in pumping is entirely wasted. The state of the air, as to dryness, is therefore an important consideration in fixing the time when this operation is to be performed; and an attentive examination of its state, by means of the hygrometer, might be productive of some economy of labour.

(37.) In some countries, where wood is scarce, the evaporation of salt water is carried on by a large collection of ropes which are stretched perpendicularly.

The water passing down them, deposits the sulphate of lime which it held in solution, and gradually incrusts the ropes, so that in the course of twenty years, when they are nearly rotten, they are sustained by the surrounding incrustation, thus presenting the appearance of a vast collection of small columns.

(38.) Amongst natural operations perpetually altering the surface of our globe, there are some which it would be advantageous to accelerate. The wearing down of the rocks which impede the rapids of navigable rivers, is one of this class. A very beautiful process for accomplishing this object has been employed in America. A boat is placed at the bottom of the rapid, and kept in its position by a long rope which is firmly fixed on the bank of the river near the top. An axis, having a wheel similar to the paddle-wheel of a steam-boat fixed at each end of it, is placed across the boat; so that the two wheels and their connecting axis shall revolve rapidly, being driven by the force of the passing current. Let us now imagine several beams of wood shod with pointed iron fixed at the ends of strong levers, projecting beyond the bow of the boat, as in the annexed representation.



If these levers are at liberty to move up and down, and if one or more projecting pieces, called cams, are fixed on the axis opposite to the end of each lever, the action of the stream upon the wheels will keep up a perpetual succession of blows. The sharp-pointed shoe striking upon the rock at the bottom, will continually detach small pieces, which the stream will immediately carry off. Thus, by the mere action of the river itself, a constant and most effectual system of pounding the rock at its bottom is established. A single workman may, by the aid of a rudder, direct the boat to any required part of the stream; and when it is necessary to move up the rapid, as the channel is cut, he can easily cause the boat to advance by means of a capstan.

(39.) When the object of the machinery just described has been accomplished, and the channel is sufficiently deep, a slight alteration converts the apparatus to another purpose almost equally advantageous. The stampers and the projecting pieces on the axis are removed, and a barrel of wood or metal, surrounding part of the axis, and capable, at pleasure, of being connected with, or disconnected from the axis itself, is substituted. The rope which hitherto fastened the boat, is now fixed to this barrel; and if the barrel is loose upon the axis, the paddle-wheels make the axis only revolve, and the boat remains in its place: but the moment the axis is attached to its surrounding barrel, this begins to turn, and winding the rope upon itself, the boat is gradually drawn up against the stream; and may be employed as a kind of tug-boat for all the vessels which have occasion to ascend the rapid. When the tug-boat reaches the summit the barrel is released from the axis, and friction being applied to moderate its velocity, the boat is allowed to descend.

CHAP. VII.

EXERTING FORCES TOO GREAT FOR HUMAN POWER, AND EXECUTING OPERATIONS TOO DELICATE FOR HUMAN TOUCH.

(40.) IT requires some skill and a considerable apparatus to enable many men to exert their whole force at a given point, and when this number amounts to hundreds or to thousands, additional difficulties present themselves. If ten thousand men were hired to act simultaneously, it would be exceedingly difficult to discover whether each exerted his whole force, and consequently, to be assured that each man did the duty for which he was paid. And if still larger bodies of men or animals were necessary, not only would the difficulty of directing them become greater, but the expense would increase from the necessity of transporting food for their subsistence.

The difficulty of enabling a large number of men to exert their force at the same instant of time has been almost obviated by the use of sound. The whistle of the boatswain occasionally performs this service; and in removing, by manual force, the vast mass of granite, weighing above 1400 tons, on which the equestrian figure of Peter the Great is placed at St. Petersburgh, a drummer was always stationed on its summit to give the signal for the united efforts of the workmen.

An interesting discovery was made a few years since, by Champollion, of an ancient Egyptian drawing, in which a multitude of men appeared harnessed to a huge block of stone, on the top of which stood a single individual with his hands raised above his head, apparently in the act of clapping them, for the same purpose of insuring the exertion of their combined force at the same moment of time.

(41.) In all our larger manufactories numerous instances occur of the application of the power of steam to overcome resistances which it would require far greater expense to surmount by means of animal labour. The twisting of the largest cables, the rolling, hammering, and cutting large masses of iron, the draining of our mines, all require enormous exertions of physical force continued for considerable periods of time. Other means are had recourse to when the force required is great, and the space through which it is to act is small. The hydraulic press of Bramah can, by the exertion of one man, produce a pressure of 1500 atmospheres, and with such an instrument a hollow cylinder of wrought iron three inches thick has been burst. In rivetting together the iron plates out of which steam engine boilers are made, it is necessary to produce as close a joint as possible. This is accomplished by using the rivets red hot: while they are in that state the two plates of iron are rivetted together, and the contraction which the rivet undergoes in cooling draws them together with a force which is only limited by the tenacity of the metal of which the rivet itself is made.

(42.) It is not alone in the greater operations of the engineer or the manufacturer, that those vast powers which man has called into action, in availing himself of the agency of steam, are fully developed. Wherever the individual operation demanding little force for its own performance is to be multiplied in almost endless repetition, commensurate power is required. It is the same "giant arm which "twists the largest cable," that spins from the cotton plant an "almost gossamer thread." Obedient to the hand which called into action its resistless powers, it contends with the ocean and the storm, and rides triumphant through dangers and difficulties unattempted by the older modes of navigation. It is the same engine that, in its more regulated action, weaves the canvass it may one day supersede; or, with almost fairy fingers, entwines the meshes of the most delicate fabric that adorns the female form.*

(43.) The Fifth Report of the Select Committee of the House of Commons on the Holyhead Roads furnishes ample proof of the great superiority of steam vessels. The following extracts are taken from the evidence of Captain Rogers, the commander of one of the packets :—

"*Question.* Be so good as to acquaint the committee in "what manner the communication has been kept open "between Holyhead and Dublin by steam packets, and "what has been the success of the experiment of establish-"ing them on that station.

"*Answer.* We have done every thing that could be done, "*by steam boats;* and they will go, no doubt, when a sailing "vessel will not,—that has been proved.

* The importance and diversified applications of the steam-engine were most ably enforced in the speeches made at a public meeting, held (June 1824) for the purpose of proposing the erection of a monument to the memory of James Watt; these were subsequently printed.

"*Quest.* Are you not perfectly satisfied, from the ex-
"perience you have had, that the steam vessel you command
"is capable of performing what no sailing vessel can do?

"*Ans.* Yes.

"*Quest.* During your passage from Gravesend to the
"Downs could any square-rigged vessel, from a first-rate
"down to a sloop of war, have performed the voyage you
"did in the time you did it in the steam boat?

"*Ans.* No; it was impossible. In the Downs we passed
"several Indiamen, and 150 sail there that could not move
"down the Channel; and at the back of Dungeness we
"passed 120 more.

"*Quest.* At the time you performed that voyage, with the
"weather you have described, from the Downs to Milford,
"if that weather had continued twelve months would any
"square-rigged vessel have performed it?

"*Ans.* They would have been a long time about it; pro-
"bably, would have been weeks instead of days. A sailing
"vessel would not have beat up to Milford, as we did, in
"twelve months."

(44.) The process of printing on silver paper, which is necessary for bank-notes, is attended with some inconvenience, from the necessity of damping the paper previously to taking the impression. It was difficult to do this uniformly; and in the old process of dipping a parcel of several sheets together into a vessel of water, the outside sheets becoming much more wet than the others were very apt to be torn. A method has been adopted at the Bank of Ireland which obviates this inconvenience. The whole quantity of paper to be damped is placed in a close vessel from which the air is exhausted; water is then admitted and every leaf is completely wetted; the paper is then removed to a press, and all the superfluous moisture is squeezed out.

CHAP. VIII.

REGISTERING OPERATIONS.

(45.) ONE of the most singular advantages we derive from machinery is in the check which it affords against the inattention, the idleness, or the knavery, of human agents. Few occupations are more wearisome than counting a series of repetitions of the same fact; the number of paces we walk affords a tolerably good measure of distance passed over, but the value of this is much enhanced by possessing an instrument, the pedometer, which will count for us the number of steps we have made. A piece of mechanism of this kind is sometimes applied to count the number of turns made by the wheel of a carriage, and thus to indicate the distance travelled: an instrument similar in its object, but differing in its construction, has been used for counting the number of strokes made by a steam-engine, and the number of coins struck in a press. One of the simplest instruments for counting any series of operations, was contrived by Mr. Donkin.*

(46.) Another instrument for registering is used in some establishments for calendering and embossing. Many hundred thousand yards of calicoes and stuffs pass weekly through these operations, and as the price paid for the process is small, the value of the time spent in measuring them would bear a considerable proportion to the profit. A machine has,

* Transactions of the Society of Arts, 1819, p. 116.

therefore, been contrived for measuring and registering the length of the goods as they pass rapidly through the hands of the operator, and all chance of erroneous counting is thus avoided.

(47.) Perhaps the most useful contrivance of this kind, is one for ascertaining the vigilance of a watchman. It is a piece of mechanism connected with a clock placed in an apartment to which the watchman has not access; but he is ordered to pull a string situated in a certain part of his round once in every hour. The instrument, aptly called a *tell-tale*, informs the owner whether the man has missed any, and what hours during the night.

(48.) It is often of great importance, both for regulations of excise as well as for the interest of the proprietor, to know the quantity of spirits or of other liquors which have been drawn off by those persons who are allowed to have access to the vessels during the absence of the inspectors or principals. This may be accomplished by a peculiar kind of stop-cock,—which will, at each opening, only discharge a certain measure of fluid,—the number of times the cock has been turned being registered by a counting apparatus accessible only to the master.

(49.) The time and labour consumed in guaging casks partly filled, has led to an improvement which, by the simplest means, obviates a considerable inconvenience, and enables any person to read off, on a scale, the number of gallons contained in any vessel, as readily as he does the degree of heat indicated by his thermometer. A small stop-cock is inserted near the bottom of the cask, which it connects with a glass tube of narrow bore fixed to a scale on the side of the cask, and rising a little above its top. The plug of the cock may be turned into three positions: in the first, it cuts off all communication with the cask: in the second, it opens a communication between the cask and the glass tube: and, in the third, it cuts off the connexion between the cask and the tube, and opens a communication between the tube and any vessel held beneath the cock to receive its contents. The scale of the tube is graduated by opening the communication between the cask and tube and pouring into the cask a gallon of water. A line is then drawn on the scale opposite the place in the tube to which the water rises. This operation is repeated, and at each successive gallon a new line is drawn. Thus the scale being formed by actual measurement,* both the proprietor and the excise officer see, on inspection, the contents of each cask, and the tedious process of guaging is altogether dispensed with. Other advantages accrue from this simple contrivance, in the great economy of time which it introduces in making mixtures of different spirits, in taking stock, and in receiving spirit from the distiller.

(50.) The gas-meter, by which the quantity of gas used by each consumer is ascertained, is another instrument of this kind. They are of several forms, but all of them intended to register the number of cubic feet of gas which has been delivered. It is very desirable that these meters should be obtainable at a moderate price, and that every consumer should

* This contrivance is due to Mr. Henneky, of High Holborn, in whose establishment it is in constant employment.

employ them; because, by making each purchaser pay only for what he consumes, and by preventing that extravagant waste of gas which we frequently observe, the manufacturer of gas will be enabled to make an equal profit at a diminished price to the consumer.

(51.) The sale of water, by the different companies in London, might also, with advantage, be regulated by a different kind of meter. If such a system were adopted, much water which is now allowed to run to waste would be saved, and an unjust inequality between the rates charged on different houses by the same company be avoided.

(52.) Another subject to which machinery for registering operations is applied with much advantage is the determination of the average effect of natural or artificial agents. The mean height of the barometer, for example, is ascertained by noting its height at a certain number of intervals during the twenty-four hours. The more these intervals are contracted, the more correctly will the mean be ascertained; but the true mean ought to participate in each momentary change which has occurred. Clocks have been proposed and made for this purpose, and the principle adopted has been that of moving a sheet of paper, slowly and uniformly, before a pencil fixed to a float upon the surface of the mercury in the cup of the barometer. Sir David Brewster proposed, several years ago, to suspend a barometer, and swing it as a pendulum. The variations in the atmosphere would thus alter the centre of oscillation, and the comparison of such an instrument with a good clock, would enable us to ascertain the mean altitude of the barometer during any interval of the observer's absence.*

Instruments might also be contrived to determine the average force of traction of horses,—of the wind,—of a stream,—or of any other irregular and fluctuating effort of animal or natural force.

(53.) There are several instruments contrived for awakening the attention of the observer at times previously fixed upon. The various kinds of alarums connected with clocks and watches are of this kind. In some instances it is desirable to be able to set them so as to give notice at many successive and distant points of time, such as those of the arrival of given stars on the meridian. A clock of this kind is used at the Royal Observatory at Greenwich.

Repeating clocks and watches may be considered as instruments for registering time, which communicate their information only when the owner requires it, by pulling a string, or by some similar application.

* About seven or eight years since, without being aware of Sir David Brewster's proposal, I adapted a barometer, as a pendulum, to the works of a common eight-day clock; it remained in my library for several months, but I have mislaid the observations which were made.

CHAP. IX.

ECONOMY OF THE MATERIALS EMPLOYED.

(54.) THE precision with which all operations by machinery are executed, and the exact similarity of the articles thus made, produce a degree of economy in the consumption of the raw material which is in some cases of great importance. The earliest mode of cutting the trunks of a tree into planks, was by the use of the hatchet or the adze. It might, perhaps, be first split into three or four portions, and then each portion was reduced to a uniform surface by those instruments. With such means the quantity of plank produced would probably not equal the quantity of the raw material wasted by the process: and, if the planks were thin, would certainly fall far short of it. An improved tool, the saw, completely reverses the case: in converting a tree into thick planks, it causes a waste of a very small fractional part; and even in reducing it to planks, of only an inch in thickness, it does not waste more than an eighth part of the raw material. When the thickness of the plank is still further reduced as is the case in cutting wood for veneering, the quantity of material destroyed again begins to bear a considerable proportion to that which is used; and hence circular saws, having a very thin blade, have been employed for such purposes. In order to economize still further the more valuable woods, Mr. Brunel contrived a machine which, by a system of blades, cut off the veneer in a continuous shaving, thus rendering the whole of the piece of timber available.

(55.) The rapid improvements which have taken place in the printing-press during the last twenty years, afford another instance of saving in the materials consumed, which is interesting from its connexion with literature, and valuable because admitted and well ascertained by measurement. In the old method of inking type, by large hemispherical balls stuffed and covered with leather, the printer, after taking a small portion of ink from the ink-block, was continually rolling them in various directions against each other, in order that a thin layer of ink might be uniformly spread over their surface. This he again transferred to the type by a kind of rolling action. In such a process, even admitting considerable skill in the operator, it could not fail to happen that a large quantity of ink should get near the edges of the balls, which not being transferred to the type became hard and useless, and was taken off in the form of a thick black crust. Another inconvenience also arose,—the quantity of ink spread on the block not being regulated by measure, and the number and direction of the transits of the inking-balls over each other depending on the will of the operator, and being irregular, it was impossible to place on the type a uniform layer of ink, of exactly the quantity sufficient for the impression. The introduction of cylindrical rollers of an elastic substance, formed by the mixture of glue and treacle, superseded the inking-balls, and produced considerable saving in the consumption of ink:—but the most perfect economy was only to be produced by mechanism. When printing-presses, moved by the power of steam, were introduced, the action of these rollers was found well adapted to the performance of the machine; and a reservoir of ink was formed, from which one roller regularly abstracted a small quantity at each impression. From three to five other rollers spread this portion uniformly over a slab, (by most ingenious contrivances varied in almost each kind of press,) and another travelling roller, having fed itself on the slab, passed and repassed over the type just before it gave the impression to the paper.

The following is an account of the results of an accurate experiment upon the effect of the process just described, made at one of the largest printing establishments in the metropolis.*—Two hundred reams of paper were printed off, the old method of inking with balls being employed; two hundred reams of the same paper, and for the same book, were then printed off in the presses which inked their own type. *The consumption of ink by the machine was to that by the balls as four to nine, or rather less than one half.* In order to shew that this plan of inking puts the proper quantity of ink upon the type, we must prove, first,—that it is not too little: this would soon have been discovered from the complaints of the public and the booksellers; and, secondly,—that it is not too much. This latter point is satisfactorily established by a reference to the frequency of the change of what is called the *set-off sheet*, in the old method. A few hours

* This experiment was made at the establishment of Mr. Clowes, in Stamford Street.

after one side of a sheet of paper has been printed upon, the ink is sufficiently dry to allow it to receive the impression upon the other; and, as considerable pressure is made use of, the tympan on which the side first printed is laid, is guarded from soiling it by a sheet of paper called the *set-off sheet.* This paper receives in succession every sheet of the work to be printed, and acquires from them more or less of the ink, according to their dryness, or the quantity upon them. It was necessary in the former process, after about one hundred impressions, to change the *set-off sheet,* which in that time became too much soiled for further use. In the new method of printing by machinery, no *set-off sheet* is used, but a blanket is employed as its substitute; this does not require changing above once in five thousand impressions, and instances have occurred of its remaining sufficiently clean for twenty thousand. Here, then, is a proof that the quantity of superfluous ink put upon the paper in machine-printing is so small, that if multiplied by five thousand, and in some instances even by twenty thousand, it is only sufficient to render useless a single piece of clean cloth.*

* In the very best kind of printing, it is necessary, in the old method, to change the set-off sheet once in twelve times. In printing the same kind of work by machinery, the *blanket* is changed once in 2000.

CHAP. X.

OF THE IDENTITY OF THE WORK WHEN IT IS OF THE SAME KIND, AND ITS ACCURACY WHEN OF DIFFERENT KINDS.

(56.) NOTHING is more remarkable, and yet less unexpected, than the perfect identity of things manufactured by the same tool. If the top of a circular box is to be made to fit over the lower part, it may be done in the lathe by gradually advancing the tool of the sliding-rest; the proper degree of tightness between the box and its lid being found by trial. After this adjustment, if a thousand boxes are made, no additional care is required; the tool is always carried up to the stop, and each box will be equally adapted to every lid. The same identity pervades all the arts of printing; the impressions from the same block, or the same copper-plate, have a similarity which no labour could produce by hand. The minutest traces are transferred to all the impressions, and no omission can arise from the inattention or unskilfulness of the operator. The steel punch, with which the card wadding for a fowling-piece is cut, if it once perform its office with accuracy, constantly reproduces the same exact circle.

(57.) The accuracy with which machinery executes its work is, perhaps, one of its most important advantages: it may, however, be contended, that a considerable portion of this advantage may be resolved into saving of time; for it generally happens, that any improvement in tools increases the quantity of work done in a given time. Without tools, that is, by the mere efforts of the human hand, there are, undoubtedly, multitudes of things which it would be impossible to make. Add to the human hand the rudest cutting-instrument, and its powers are enlarged: the fabrication of many things then becomes easy, and that of others possible with great labour. Add the saw to the knife or the hatchet, and other works become possible, and a new course of difficult operations is brought into view, whilst many of the former are rendered easy. This observation is applicable even to the most perfect tools or machines. It would be *possible* for a very skilful workman, with files and polishing substances, to form a cylinder out of a piece of steel; but the time which this would require would be so considerable, and the number of failures would probably be so great, that for all practical purposes such a mode of producing a steel cylinder might be said to be impossible. The same process by the aid of the lathe and the sliding-rest is the every-day employment of hundreds of workmen.

(58.) Of all the operations of mechanical art, that of turning is the most perfect. If two surfaces are worked against each other, whatever may have been their figure at the commencement, there exists a tendency in them both to become portions of spheres. Either of them may become convex, and the other concave, with various degrees of curvature. A plane surface is the line of separation between convexity and concavity, and is most difficult to hit; and it is more easy to make a good circle than to produce a straight line. A similar difficulty takes place in figuring specula for telescopes; the parabola is the surface which separates the hyperbolic from the elliptic figure, and is the most difficult to form. If a spindle, not cylindrical at its end, is pressed into a hole not circular, and if the spindle be kept constantly turning, there is a tendency in these two bodies so situated to become conical, or to have circular sections. If a triangular pointed piece of iron be worked round in a circular hole the edges will gradually wear, and it will become conical. These facts, if they do not explain, at least illustrate the principles on which the excellence of work formed in the lathe depends.