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THE INJECTOR: HOW AND WHY IT WORKS.

A Paper for Young Engineers.

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THE author, before entering into the subject which is to be considered to-night, wishes it to be distinctly understood that the paper is specially intended for young engineers. He had every confidence that he might trespass on the patience and claim the indulgence of the older members for the plain and perhaps old-fashioned methods of treatment. He freely confessed that the attempt made to give such an explanation as will make the working of the instrument before them—clear to any practical mechanic—had been to him by no means easy, in fact, the various principles involved, all of which are more or less complex, make it anything but plain sailing. He had gone into matters which may to some appear superfluous, but this had been done from the conviction that it was necessary to do so to make it understood. Another reason is that we can scarcely devote too much time when attempting to explain the fundamental principles of mechanics. In connection with this he would like to say a few words. In our worthy President's address, delivered last meeting, he very properly made special reference to the benefits which the rising generation of engineers would derive from our system of technical education, and he gave the Parliament of this Colony great credit (which it undoubtedly deserves) for the efforts made to have this system as perfect as possible. The progress of technical teaching has during the last few years been exceptionally rapid, and no doubt the future development and extension will be even more so. There was, however, one point in connection with it that in his judgment was a mistake, and the present meeting and the present company appeared to him to be an appropriate opportunity of directing attention to it. What he complained of was certainly not confined to this colony or any particular country—we are neither better nor worse than others; for the fault is just as prevalent in the universities and technical schools of England, Germany, and France, as it is in Sydney, so that he was speaking in a national, or, rather, in a universal sense. Having for many years had exceptional opportunities of judging, he respectfully but decidedly held that, so far as engineers are concerned, the system attempts too much. Teachers shoot too high and too often, they cover too much ground in a given time. The multiplicity of subjects, the immense number of rules and formulæ, and the rapidity with which they pass from one subject to another, is far too much for any ordinary capacity, and often results in such a confusion of ideas that a large percentage of students get hopelessly mixed, discouraged, disheartened, drop behind, and retire disappointed. To know a few mechanical principles thoroughly, to feel you can explain and, if required, apply them to your daily work, is infinitely more useful and valuable than having a smattering of many things but a real knowledge of none.

Speaking from a fair experience, he felt bound to state that in many cases the engineering knowledge acquired at technical schools could be best expressed by comparing it to the parson's sermon, which was characterised as being remarkable for its length, but not for its depth; and if the number of subjects were halved, and the time allowed for studying them doubled, they would turn out better men. Rapid teaching is not conducive to thoroughness, and if this speed was slackened he felt sure it would be a national benefit. These remarks were not made in any spirit of fault finding, for, as many of them knew, few men in Sydney had taken a deeper interest or devoted more time to the initiation of this education than he had. What had been said was from conviction, and had been specially referred to because it is of such importance that in the discussion which will follow the reading of this paper they would get an expression of opinion from men who were well qualified to judge, an opinion that may carry weight enough so that the system may be modified to benefit all concerned. Referring to the teachers generally, there is no doubt that a very large percentage of them are exceptionally clever men—having rare natural ability, which has been carefully cultivated; but they would agree with him when he said that men of exceptional talent do not always make the best teachers, because, gifted as they are with so keen a perception, they can in a very short time and with comparative ease master complex principles and problems, which to an ordinary brain would be a source of great difficulty, requiring patient study and a much longer time; hence it is that so many clever men fail to impart to others the knowledge they possess, because their method of teaching assumes the ability and perception of the average student to be much greater than it really is, that it is something akin to their own, consequently they fire too high, miss the mark, and their labour is lost. It is the same with many of our text books, they simply bristle with technicalities, and in many cases, as far as the student is concerned, their tendency is to repel rather than to attract. Of course there are exceptions, such men as Fairbairn, Faraday, Tyndall, Ball, and others, whose knowledge, and knack of imparting it, is in happy combination; and in such hands even the most abstruse subject is made interesting and instructive.

So far as our Association is concerned, he believed we had scarcely done justice to our younger members. Although many really good papers have been read and discussed to our advantage, still in many of them the "matter" was more or less complex, and it is desirable that we should have two or three papers or lectures every session on some practical subject for their special benefit. This could be easily managed, as many of our members are well qualified to take this in hand. This was scarcely a suggestion, because in the present effort he had the necessity of doing something of this kind before him, in fact, he looked upon it as his share during the present session, and there should be no difficulty in getting one or two more.

In the preparation of the paper he had been very forcibly reminded of the swift though silent flight of time. He could scarcely believe—could not realise—that twenty-one years had passed away since some half a dozen mechanics met together in a little room in the old Masonic Hall in York Street, to consider the possibility of forming some kind of a society where they could meet together and discuss the engineering questions of the day; which would not only supply a long-felt want, but would be mutually beneficial to all concerned, and to the colony generally. At this time there were practically no means, very few facilities, and little encouragement to acquire knowledge, for the so-called Mechanics' Institutes had degenerated and become in many cases mere circulating libraries, having signally failed to carry out the object for which they were originally intended.

Knowing this, we had sense enough to realise that somebody must do something—hence the meeting held in 1870, just twenty-one years ago, the result of which was the founding of the Engineering Association of New South Wales. Of those who were present at that meeting, the majority have crossed the dark river, and those who are left and who at that time were in vigorous manhood have also passed the meridian, and are now on that side of life where the "shadows are lengthening." The original founders of the Institute were (as far as the author's memory serves him): John Fife, William Davidson, Charles Halliday, George Davidson, John Laing, Thomas Ferguson, Norman Selfe, Peter Hunter, and himself. Looking back, old familiar faces, and old familiar voices seem very near to-night, but he felt sure members would not misconstrue his motive in referring to these things, for he considered it a privilege to have this opportunity of standing there after all these years, and of being able to testify to the sure, steady, and very material progression which the Society has made, and which has been largely due to those who now sleep so soundly. In the early days one of the greatest difficulties was to get suitable papers, or indeed, papers at all, and to meet this trouble they introduced a system of asking and answering questions in rather a novel way. A box was provided into which any member could at any time, and without signature, drop any scientific or mechanical question. This box (in the absence of a paper) was at the general meeting opened by the President, who read out the questions. This plan answered admirably, many interesting discussions resulting, in fact he sometimes thought the system might be revived with advantage. It was about seventeen years ago that a question was read out asking the explanation of the principle on which the Injector worked, and at the following meeting he endeavoured to explain it by reading a short paper. What became of the paper he did not know, as they had no printing done at that time, everything was of necessity carried out in a rather primitive style; but lately several inquiries from our young engineers, asking where they were likely to get an explanation of how and why this curious little instrument worked, resulted in the writing of this paper.

In looking over the various standard works, there is very little information for the practical engineer as to how or why it works. All, or nearly all, the books confining their remarks to the details of construction, and the various improvements which have been made from time to time. In a paper read many years ago, in 1865, before the Institute of Civil Engineers by Mr. John England, on "The Injector," a very interesting discussion took place which lasted four nights, and in which such historical names as Henry Maudsley, Sir F. Bramwell, Dr. Joule, Sir William Armstrong, C. W. Siemens, George Bidder, Scott, Russell, and others took part. The paper was a most complex affair, founded upon an undoubted fallacy, because the author assumed that steam possessed certain qualities which it does not, and on this false assumption he erected an elaborate superstructure with a number of scientific tables and perplexing formulæ. Of course it was severely but courteously handled, and Siemens, Bramwell, and others, gave very good explanations of the principle of its working, but the large majority had a poor conception of its true nature. Since that time there have been very few papers written in connection with it, at least he could not find any with the exception of one by Mr. Savill, read before the Institution of Mechanical Engineers in 1884, on his "Patent Automatic Injector," relating principally to its application as an exhaust injector, to which reference will be made further on.

In this paper, which was remarkably short, he gave no explanation whatever as to how it worked, and in the discussion which followed, a number of members expressed regret that no real practical explanation was available. Now it may result that the present attempt will be as vague and unprofitable as the rest, and if so, he should have the satisfaction of having failed in good company; and, if successful in making it clearer than before, his object in writing it would be attained, and this would be ample recompense for any and all the trouble.

You all know what a paradox is, it may be defined as something seemingly absurd or contradictory, yet true in fact; something apparently inconsistent with known principles, and yet when explained found to be perfectly correct. In mechanics we have an example of this in the well known hydrostatic paradox, where a quantity of water, no matter how small, can be made to balance a quantity, no matter how large. This fact that the weight of one pound of water may be simply applied to produce a pressure of hundreds and thousands of pounds is what is termed a paradox; but there is nothing paradoxical about it, for it is simply a hydrostatic lever, where a very small weight on the long arm will balance or overcome a very large weight on the short arm; and in this we have a more perfect illustration of leverage than in the solid lever moving about a fulcrum. In doing this there is no increase of force, because it only amounts to resolving a small force moving through a great distance into a large force moving through a proportionately small distance.

The Injector might very properly be considered to be a mechanical paradox: for its action is an apparent contradiction, a seeming impossibility, and when first brought out by Giffard in 1852 was subjected to the most severe criticism, and even ridiculed by many who were assumed to be competent judges. That steam could be taken from the steam-space of any boiler, and by passing it through this modest little instrument it would have power to force water into the water-space of the same boiler against its own, and more than its own, initial pressure seemed contrary to all preconceived notions, and to most people appeared to be a palpable absurdity, and they argued something like this: How was it possible to take steam from the steam-space of a boiler when the steam-guage is showing 60lb. and force it into the water-space, where the actual pressure of steam and water may be, and often is, 65lbs.? The thing is contrary to common sense, and cannot be done. Still it was, and, as you all know, is done every day, and the possibility of being able to do this is a very beautiful, yet very practical, application of natural laws, and of certain properties of steam and water which are now better understood than they were forty years ago.

So far as he could judge, the invention of the Injector was rendered possible by the two great discoveries of Galileo—

discoveries of supreme importance—supplying us, as they undoubtedly do, with the only true methods of measuring work and calculating time correctly. It was from the top of the now historical Leaning Tower of Pisa that Galileo first demonstrated that all bodies falling from the same height practically attain the same velocity independent of their weight. He had previously experimented on a small scale to test the truth of this principle, and he thoroughly satisfied himself by dropping two balls—one iron, the other wood—from the top of the tower and finding that practically they touched the ground at the same instant. This Tower of Pisa is also somewhat of a paradox in its way, it is about one thousand years old, 180 feet high, 50 feet in diameter, and it leans 16 feet out of perpendicular, but, as its centre of gravity does not overhang the base, it is to all appearance good for another thousand years. The other discovery of Galileo was also made in the Pisa Cathedral. He noticed that the motion of the swinging censor lamps suspended from the roof of the building was wonderfully uniform, and it occurred to him that such an instrument in a modified form might be useful and valuable for measuring time, as well as for medical observations on the human pulse. The means he used to demonstrate the correctness of his theory, although not what would be adopted in these modern days, were at once sensible, ingenious, and eminently practical. He constructed a single pendulum and allowed it to perform one hundred vibrations, its amplitude, or length of swing being two feet, and he counted his pulse during the time, he then increased its amplitude or swing to four feet, and although travelling through twice the space he found the number of pulsations to be precisely the same in both cases. By this means he proved very conclusively that within certain limits the motion of a pendulum was isochronous, that is, it takes exactly the same time to make a small swing as a large swing, and this remarkable property is the foundation of correct time keeping. By experiment he also found that in addition to the pendulum being independent of its amplitude, it was unaffected by its weight and also of the material of which it is made. A ball of lead was found to swing in the same time as a ball of brass, and both in the same time as a ball of iron or wood. Thus you see that the discoveries of Galileo are intimately connected with each other, because the reason why all bodies fall to the ground in equal times is precisely the cause which makes the pendulum swing independent of its weight and the material of which it is constructed. What does affect the pendulum is its length, for when one of two pendulums is one-fourth the length of the other, the short one will make two oscillations while the long pendulum makes one; and if we had three pendulums whose lengths were 27 feet, 12 feet, and 3 feet, respectively, these numbers are in the proportions of 9, 4, and 1; and the times of oscillations are proportional to 3, 2, 1; hence we see that the time of vibration is always proportional to the square root of the length. At the same time we must not forget that although practically the time is as the square root of the length, the time also depends on the action of gravity, for if gravity be increased, the time of vibration is lessened; for whatever this force is it always acts from the centre and not from the surface of the earth, and as this distance varies, owing to the earth's shape, if we wish to make a pendulum beat seconds in any particular place, the action of gravity, or what is the same thing, the velocity which a body would acquire at the end of the first second when falling freely from a state of rest, must always form an important factor in the problem. For example, it has been calculated, and the calculation has been verified and confirmed by actual experiment, that a pendulum beating seconds at the equator had to be lengthened nearly a quarter of an inch to beat seconds at Spitzbergen, and it is in this way that the variation of the intensity of gravity is measured.

What has been said respecting the discoveries of Galileo, the laws which govern falling bodies and the action of the pendulum, has been rendered necessary from the fact that the working of the Injector depends on the same principle, as the author will endeavour to show. First of all, before anyone can have a clear idea oı understand and appreciate this beautiful application of natural law to mechanical work, he must have some conception of the pressure, density, and temperature of steam—its three most important properties. The ratios and relationships existing between them are no doubt somewhat difficult and puzzling; but, when patiently studied and mastered, every engineer will find the knowledge acquired a splendid asset, which will continually assert itself in everyday practice. In our daily life we are surrounded by many wonderful things, to which we are so accustomed that we take or look upon them as a matter of course, and amongst them all there is nothing more wonderful than the result of confining boiling water. In order that steam should exist in bubbles in the interior of the water, it must be able to resist two things—First, the weight of the water above it; and, second, the pressure of the atmosphere above it. Some of the members present will recollect the days when all boilers were fitted with atmospheric valves to prevent them collapsing. How comes it then, as Tyndall, in his book on "Heat, a Mode of Motion," very naturally asks: "How is it that so delicate a thing as a steam bubble can exist and retain its form on the surface of boiling water?" Simply because the elastic force of the steam within is exactly equal to the pressure of the atmosphere; the steam bubble is pressed between two cushions, which exactly balance each other. If the steam were strongest the bubble would burst, and if the air pressure predominated, it would collapse. Therefore the proper definition of boiling point is: that temperature at which the tension of its vapour exactly balances the pressure of the air. When water is vaporised its whole nature is entirely changed, and as steam it possesses qualities totally different from the water from which it was generated, and it was because Giffard thoroughly understood what this difference meant that he was enabled to construct his