SOME POINTS IN CYCLE CONSTRUCTION.

BY MR. F. J. OSMOND, OF BIRMINGHAM.

The rapid development of the modern Bicycle is mainly if not entirely due to the influence of the racing track in securing the extinction of the least fit. The advance has been made by a lengthy and expensive process of trial and error; but this process would have been far more tedious and expensive, if it had been left to the judgment of the average rider to decide what constituted fitness. It is in the final struggle at the end of a well-contested race that the fine shades of difference in the speed of machines have been discriminated. This method of experiment may eventually give place to others more scientific and more exact; but the latter are hardly likely to be so popular.

It is now generally understood that the property of speed, possessed in such various degrees by cycles, is mainly a negative property: that is, it is the absence of any means of dissipating the energy transmitted through the mechanism; in fine the whole question is one of efficiency. The best machine both for racing and for ordinary riding is that which is most efficient. The principal causes of inefficiency in a cycle are—want of rigidity, and friction: a cycle which should be absolutely rigid and entirely without friction would have an efficiency of 100 per cent.; that is to say, it represents an ideal perfection which could not be exceeded, and cannot actually be attained.

Rigidity.—Of these two sources of inefficiency, it is probable that want of rigidity is the most important. It is in this particular that cycles differ far more than in friction; and it is invariably found that the more rigid machine is also the faster. The cause is twofold.

Firstly, the work done in springing the frame out of shape at each stroke of the foot is not spent in driving at the end of the down-stroke, but only in lifting the foot at the beginning of the upstroke. The amount of exertion wasted in this way may be fairly estimated by sitting on a machine with the wheels fixed, and alternately applying and relieving the pressure of the foot on the pedal: the more springy the machine, the greater will be the fatigue experienced. Secondly, the springing of the frame causes a general condition of instability, due partly to the alteration of the balance through lateral movement of the pedals, and partly to the wheels being forced out of line, thereby causing the machine to swerve from side to side, instead of running a true course. Although the loss of efficiency from this cause may seem slight, the sense of instability has a disastrous effect in marring a sudden effort or in aggravating a steep hill.

Friction.—In a machine with well-constructed bearings, friction is mainly due to the chain. The consequent loss has been variously estimated; as low as 1 per cent. of the total power has been recently given. If this were correct, chain driving would be the most efficient means of transmitting power at present known. Probably however the loss was measured when the chain was not doing any work, which would make the test fallacious. About 5 per cent. seems nearer the truth. The means of avoiding these various sources of inefficiency may be considered in detail; and at the same time the means by which the ordinary stresses in a vertical plane may be met with a minimum of material.

Factor of Safety.—It has been said that the factor of safety for a cycle frame is about $1\frac{1}{2}$. If this is understood to mean that a machine designed for a 12-stone rider should not be ridden by one exceeding 15 stone, it is probably not far out in most cases; yet a well built frame will carry a steady load of at least ten times this weight without injury. The difference between these two statements is due to the fact that the front part of the frame is exposed to shocks which must cause bending stresses near the head H, Fig. 1,

Plate 48; for if the two front tubes L and U are arranged so that their axes intersect vertically above the axle of the front wheel, the stresses are only pure tension and compression, so long as the force acting through the front axle is purely vertical. It is evident that this is not the case when the front wheel meets a brick or other obstacle which represents a force acting obliquely, as at O; whilst when the wheel drops on the other side of the obstacle, there is a shock which is vertical, as indicated at V. It is thus impossible to avoid bending; and the best compromise is obtained by making the axes of the two tubes meet some distance behind the perpendicular through the front axle, as shown in Fig. 1. This consideration is sufficient to justify the present shape of frame with short head H and horizontal top-tube U. Any considerable obstacle surmounted by the front wheel causes two distinct shocks, the first oblique and the second vertical; and these shocks will in general tend to bend the front tubes first in one direction and then in the other. The bending moments are greatest close to the head, just where the tubes have been weakened by brazing; it is therefore necessary to provide some local strengthening. This the author gives by shrinking a reinforcement about 5 inches long upon the outside of the tube ends, as shown full size in Fig. 6, Plate 50; the tubes are brazed together at the ends, tapered in a lathe, and the whole then brazed into the lug, as shown in Fig. 1. By this means the part weakened by the brazing is kept within the reinforcement, and breakage is practically impossible.

Large Tubes.—Although there is an evident advantage in increasing the diameter of tubes subjected to bending and tension, yet, as the thickness must be reduced in order to retain the same weight, a limiting ratio of diameter to thickness is soon reached, which cannot be exceeded without danger of the tube failing through buckling induced by some small local stress due to dents, etc. This ratio is much smaller when the tubes are curved, as in handle-bars, which if made of too thin metal will fail at the bend, and not at the junction with the stem where they ought to fail first if their strength is calculated from the bending moment only. In

multicycles, where heavier tubes are necessary, the diameters may be considerably increased, with great advantage to the general strength and rigidity. For tandem and triplet cycles the author makes tubes 25 per cent. larger in diameter than for single machines, which gives about 50 per cent. more rigidity for the same weight.

Aluminium Frames.—The advantages of aluminium and its alloys, as compared with steel, have been so often urged that a few facts may be interesting. The best aluminium alloys have about 16 per cent. less strength and rigidity when drawn into tube than a steel tube of the same weight and outside diameter; but owing to its much greater thickness the aluminium tube can be made of larger diameter without danger of buckling. For handle-bars aluminium has greater advantages; and if it could be readily plated it would be really valuable for this purpose. The difficulty of jointing is much against it in most cases. For the comparison of strength and rigidity the tubes tested were both 1 inch outside diameter and practically of the same weight per foot; the steel tube was 20 gauge or 0.036 inch thick, and the aluminium alloy 12 gauge or 0.110 inch thick. The superiority of the steel tube was due to its greater mean diameter; making allowance for this, the strengths and stiffnesses of the two materials are nearly equal. The maximum stress in the steel tube was 52 tons per square inch, and in the aluminium alloy 18.7 tons per square inch. The effect of a brazing heat was to reduce the strength of the steel by 45 per cent., thus bringing down its maximum stress to 28.6 tons per square inch; the stiffness was unaffected.

Testing of Tubes.—In testing tubes it is necessary to take special precautions in order to avoid buckling by local stress. For example, if the tube is supported at the ends and loaded at the centre, it should be of considerable length, say 3 feet for 1 inch diameter; and the load should be suspended by a broad leather strap, so as to distribute the pressure over a large surface. Through the neglect of these precautions the results of many published tests have been rendered entirely misleading. The advantages so often claimed for

"webbed" tubes are apparent only when the tube is tested in short lengths and loaded in the centre; under these conditions a plain tube is crushed in at the point where the load is applied, which is also the point of maximum compression stress due to the bending; it therefore fails prematurely from a local stress, which has no counterpart in the working stresses of a cycle. When tested with proper precautions, webbed tubes are both weaker and less rigid, weight for weight, than plain tubes: a result which accords with theory. The same may be said of various other sections. It is in many cases better to test by brazing a solid plug into one end of the tube, and having clamped this end, to load the other end; in this way all unfair stress is avoided. Corrugated tubes have the advantage of resisting local stress better than plain tubes; but they are less rigid, weight for weight, and present difficulties in jointing, as seen in Figs. 7 and 8, Plate 50. Nickel steel is as rigid as carbon steel, and has the advantage of a higher elastic limit; it is therefore well suited for the two front tubes of a cycle, which are the most subject to vibration. In other parts, where the elastic limit is not so nearly approached, it has no advantage over ordinary steel. It is a mistake to suppose that the mildest steel is the safest under vibration; owing to its low elastic limit it is more liable to break off short from vibration than harder steel containing up to 0.8 per cent. of carbon.

Means of securing Rigidity.—In considering the design of a safety bicycle frame, too little attention is generally paid to what may be called the driving stresses: that is, those set up by the pressure of the foot upon the pedal, which causes lateral distortion of the frame. There are two distinct cases to be considered: first, when the pressure of the foot is balanced by a pull at the handle on the same side; and second, when there is no pull at the handle.

In the first case, when the pressure of the foot is balanced by a pull at the handle on the same side, the distortion is confined mainly to the front part of the frame, Plate 48, consisting of the head tube H, the upper and lower front tubes U and L, and the seat-socket tube P. Each member of this quadrilateral is subjected to both

torsion and bending. If any one of these members is so strengthened that its bending and twisting are diminished, then the strength of the adjacent members is also increased, so that much greater forces are required to produce a given distortion. Now the head tube being short compared with the other members, an increase in its thickness is accompanied by an increase in the stiffness of the frame out of all proportion to the increase of weight. This stiffness is also increased up to a certain point by shortening the head tube. The long heads in vogue a few years ago rendered the frame more springy; while the present pattern of frame, with horizontal top-tube U and comparatively short head H, is much better in this respect. The torsion of the seat-socket tube P is greatly diminished if the rear part of the frame is rigidly connected, instead of being merely bolted together. When the torsion of the head tube H and seat-socket tube P is thus minimised, rigidity is secured by providing top and bottom front tubes U and L of suitable diameter and thickness.

In the second case, when the pressure of the foot is not balanced by a pull on the handle, the distortion is not confined to the front part of the frame, but every member is twisted and bent simultaneously. The rigidity thus depends mainly on the joints throughout the frame. In Fig. 2, Plate 49, is shown the nature of the distortion observed in a machine wanting in rigidity. Here it will be seen that the wheels and the frame are no longer in the same plane; the wheel inclines to one side of the vertical, and the frame to the other, and the direction of the inclination alters at each stroke of the foot. The stresses thus set up are much the same as if the wheels were fixed, and the frame twisted by means of the seat pillar P. If the joints are made merely by flattening the ends of the tubes and then bolting up, as shown full size in Figs. 9 and 10, Plate 51, the frame is liable to be rickety; because under bending and twisting stresses such joints will give more than the whole length of the tube. This source of weakness is avoided in the author's practice by brazing the back forks F and chain stays S together, without any flattening or weakening of section, and by reinforcing the joint with a wrapping of sheet steel, as shown in Figs. 11 and 12. To the junction of the seat-socket tube the back forks are also brazed;

and the solid end-piece, after brazing in, as shown in Figs. 13 and 14, is recessed to take the seat-pillar bolt. This connection is so rigid as to permit of dispensing with the usual bridge above the back wheel. In the same way the ends of the front fork are stiffened so as to increase the lateral rigidity greatly, as compared with the usual make of flattened-tube fork-end. In the fork crown the weakest feature of the ordinary double-plate pattern is the smallness of the brazing surface, as shown half size in Fig. 3, Plate 49, which sometimes results in the tearing apart of the joint. This is remedied by fitting the fork blades into a practically continuous socket joining the crown plates, as shown in Fig. 4: thereby so greatly increasing the brazing surface as to reduce the maximum stress on the solder, and to eliminate all chance of breakage.

Chain Stays.—The chain stays are perhaps the most important part of the frame of a cycle; they are certainly the part about which the greatest difference of opinion exists. Before the extreme importance was realised of a narrow tread for constituting a straight-running machine, round chain-stays of 7-8ths inch diameter were often used, which gave ample stiffness; but now that there is a premium on every eighth of an inch under 5 inches clear width between the pedals, it is necessary to reduce this diameter to about 5-8ths inch. Now a tube of round section 5-8ths inch diameter is only about half as stiff as one 7-8ths inch diameter of the same weight, and has only about 70 per cent. of the strength. It therefore becomes necessary to use a section giving greater rigidity and strength than the ordinary round tube. The choice lies between oval, rectangular, and D sections. The last of these has been chosen by the author as the most suitable, in consideration of the nature of the stresses to be met. The weight of the rider puts the chain stays in tension; but this tension is small compared with that produced when the foot is exerting its maximum pressure on the pedal. The nature of the deformation produced by the chain tension may be investigated by tightening up the chain, and then squeezing its upper and lower spans together. It will be seen that both of the chain stays are thereby bent towards the chain side,

because, being connected by the back axle, one cannot move without the other; and the final result is a bending in four places, two on each side, as shown in Fig. 15, Plate 52, namely close to the bridge and close to the back axle. The chain stays designed by the author are shaped with a slight bend in the middle, as shown in Fig. 16, so as to clear the crank end. This construction has been criticised as causing a bending moment at that point, tending to buckle inwards the stay on the chain side; but experiment shows that the total bending moment is not a maximum at that point, and that consequently the slight inward bend does no harm. On the other hand a sharp bend near the bridge is a source of weakness, which is best guarded against by using a steel casting at this point, instead of merely bending the tube. The bending moment, which is due to the back axle not being exactly in line with the back forks in some portions of the "chain adjustment," amounts in extreme cases to about 70 inch-lbs., which means only a small stress on the **D** tubes that are used. The stress moreover is perfectly symmetrical, and causes no lateral distortion of the frame. The advantage claimed for the radial or swinging adjustment, Fig. 17, Plate 53—namely that the axle **A** is always in the centre line of the back forks **F**—is thus of small account, and is far more than counterbalanced by the want of lateral stiffness in that adjustment. By the "chain adjustment" is meant the path of the back axle **A** along the slot provided in the end of the stay **S** for the purpose of adjusting the tension of the chain, as shown full size in Fig. 17: when the back forks **F** are bolted to the axle **A**, as in the radial adjustment, the weight of the rider is taken direct by the axle; but when the frame is brazed together at this point, as in Fig. 18, the axle moves away from the point where the centre lines intersect.

D Tubes.—On the subject of **D** tubes for chain stays there exists some amount of misapprehension. They were introduced by the author partly because the flat inner side is convenient for the nuts **N** on the back axle to be locked against, Fig. 21, Plate 54; and partly because, for the same width and weight, they are more rigid than either round or oval tubes. It must be borne in mind that, in order

to attain the requisite rigidity, it is necessary in general to increase the section of chain stays beyond what is required for mere strength ; it is therefore the rigidity of the different sections that has to be compared, and not their strength. It has been argued by a recent writer on cycle construction that weight for weight a tube of semi-circular section is only 1 per cent. stronger than a tube of circular section, if both are of infinitesimal thickness. Now the **D** tubes employed by the author are not of semicircular section, and they are at least 20 gauge or 0.036 inch thick. A semicircular tube is about 23 per cent. stiffer than a circular tube, weight for weight, if both are of infinitesimal thickness ; and when the thickness becomes finite, the advantage is still greater. A 5-8ths inch semicircular tube of 20 gauge or 0.036 inch thickness is about 32 per cent. stiffer than a 5-8ths inch circular tube of the same weight, since the thickness of the latter must be about 17 gauge or 0.054 inch, and its mean diameter is therefore less. The section used by the author however is not semicircular, but much more resembles the shape of the letter from which it takes its name, as shown full size in Fig. 22, Plate 55. Theoretically a rectangular section is the best possible ; but its appearance on a cycle is so hideous as to be out of the question. If for equal weight the relative stiffness of a tube of circular section, 5-8ths inch diameter and about 17 gauge thickness, be represented by 100, then the results of tests of oval and **D** and rectangular sections, all three rolled from a round tube of 15-16ths inch diameter, will compare as follows :—

Round tube,	0.65	diameter	×	0.054	thickness,	relative stiffness	100					
Oval	„	0.65	wide	×	1.125	deep	×	0.036	thick,	„	„	119
D	„	0.65	„	1.070	„	0.036	„	„	„	„	„	136½
Rectangular	0.65	„	0.825	„	0.036	„	„	„	„	„	„	146½

It will thus be seen that the **D** section now adopted is only about 7 per cent. less stiff than the rectangular, which is the best that can be rolled out of a round tube of the same diameter and to the same width.

Various webbed sections have from time to time been proposed, and advantages have been claimed for them on the strength of tests

which mainly show resistance to local crushing in one particular direction, and give no indication whatever of the value of the section when made up into a cycle. Tests made on webbed **D** tube, by brazing a plug into one end and loading the other, show that it is 6 per cent. less strong and 15 per cent. less stiff than plain **D** tube of the same weight and external size. It is important to realise that the material of a tube should be kept as far away from the neutral axis as possible. This applies to various other sections, such as those shown in Figs. 23, 24, and 25, Plate 55.

Multicycles. — The necessity for lateral rigidity is even more apparent in multicycles than in single machines. It is found that any want of unison in the efforts of the riders has a disconcerting effect, which greatly detracts from the pace and from the power of going up hills. It is only by the employment of tubes of larger diameter that the increased distorting stresses can be properly met. The form of frame now generally adopted, shown in Fig. 19, Plate 54, was first used by the author in 1895, and has for its principal feature a horizontal tube **I** running from the bottom of the head **H**, parallel with the top tube **U** which starts from the top of the head; the lower line of tube **I** is braced by means of light diagonals to a single bottom-tube **B** of $1\frac{3}{4}$ inch diameter. This form of frame, whilst not superior in strength or rigidity to that having diagonals running from the top tube to the bottom without an intermediate tube, as shown in Fig. 20, possesses a great commercial advantage in the fact that frames can be built of different heights without altering the angles of the lugs, simply by raising the top tube **U**. It is advisable to unite the rear end of the intermediate tube **I** to the back forks by a short fork, as shown at **J** in Fig. 19, which increases the lateral rigidity. There seems to be a general tendency to duplicate the back fork **F** in multicycles; but greater rigidity can be secured by means of a single fork of large section, provided that it is properly connected to the top of the rear seat-pillar lug **L**, as shown in Fig. 19. In the same way a single tube **B** of $1\frac{3}{4}$ inch diameter connecting the various crank-brackets gives greater rigidity than the more usual arrangement of two 1-inch tubes, placed either side by side or one above the other.

Back Axle.—The method devised by the author of fixing the back axle by nuts N locking against the inner or flat side of the D-section chain-stays, as shown full size in Fig. 21, Plate 54, gives a rather wider spread to the back forks than is usual, which is an advantage in improving the bracing between the axle and the seat-pillar lug.

Chains.—The great advantage of a roller chain, shown full size in Figs. 26 and 27, Plate 55, when exposed to mud or dust, led the author to consider why the block chain, Figs. 28 and 29, was so generally admitted to be the faster of the two; and the conclusion he came to was that it is a question of smoothness of running. The roller-chain links were at least 1 inch long from centre to centre of eyes, whilst those of the block chain were alternately 0·4 and 0·6 inch. By shortening the links therefore to half an inch, he concluded that the roller chain would run more smoothly and consequently be faster than the block chain. It was found indeed that roller chains of 5-8ths inch pitch were already contemplated by the chain-makers; but as this length is slightly in excess of the longer of the block-chain links, there is no advantage in smoothness or speed. It was questioned whether the chain and wheel of half-inch pitch, shown half full size in Fig. 5, Plate 49, could be made a success in practice; but experience has fully justified the expectations on this point. The smoothness of running with gearing of this pitch is remarkable; whilst its excellent behaviour when covered with mud or dust renders a casing almost superfluous.

Gear and Crank Length.—The question of gear is so closely connected with that of crank length that they cannot properly be considered separately. For it is evident that a gear of 60 inches does not represent the same conditions with a 6-inch crank as when one of 7 inches is used; and similarly it would not be reasonable to expect that a leg 36 inches long will be suited by a length of crank which suits a leg 32 inches long. The length of crank must be decided by the rider's natural length of stride, and the ratio of multiplication of gear to length of crank must depend upon his

muscular development: both of which data may be approximately ascertained by measurement. The gear is then the product of the two factors so determined. The maximum ratio of multiplication for road riding is about twelve times, and the minimum about nine times. The maximum length of crank may be taken as about $7\frac{1}{2}$ inches, and the minimum 6 inches. Hence the gear may vary from 90 inches down to 54 inches.

Discussion.

Mr. OSMOND exhibited an extensive collection of specimens of the component parts of cycles in an unfinished state, illustrating the successive stages through which they had to pass and the nature of the work done upon them in each stage. Also various examples of finished work, and a completed bicycle of the most recent make.

Mr. T. BUDWORTH SHARP thought the construction of the frame of bicycles, like that of the locomotive, was now pretty well settled for some time to come. The great difficulty to be dealt with however was that of brazing, which, owing to the present practice of using a tube of uniform thickness throughout, weakened the frame at least as much as had been stated in the paper (page 287), namely nearly half. There were two ways of getting over that difficulty. One was to make a tube with thickened ends where the brazing took place. As an old tube-maker he believed there was no difficulty in making such tubes. If a tube were made 17 gauge or 0.054 inch thickness for the short length where the brazing took place, and the rest of the tube were 22 gauge or 0.028 inch thickness or even thinner, it would be much stronger than the present tube, and considerably lighter. The other way would be by using a mechanical fixing, and doing away with brazing altogether; because, even with a good method of brazing, a careless workman might get the metal over-heated, and it then came back practically to cast

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metal. If brazing could be avoided and a mechanical joint be substituted, the latter he considered would be practically perfect: though he admitted that no mechanical joint he knew of was as firm as a good brazed joint. The nearest approach he had yet seen to a sound brazed joint was made by placing, inside the tube which had to go inside the socket, either a light aluminium plug or else a hollow internal liner, grooved round outside by a beading tool like a tube-cutter; then by another tool, like the converse of a Dudgeon roller tube-expander, both the external socket and the tube in between were pressed right into the grooves of the internal liner. In that way the mechanical hardness made in the drawing of the metal was not lost by the heat of brazing. If the loss of the mechanical hardness could be avoided, the frame might of course be still further lightened. It could also be lightened by the use of tubes with their ends thickened to such an extent that the extra local thickness more than made up for the weakness necessarily caused by the brazing. Of the two alternative methods he preferred the use of the extra thickness at the place where the brazing was done. Frames so made were at once lighter and stronger.

Mr. OSMOND doubted whether, if a mechanical joint could be devised, it would give the same rigidity and security as a brazed joint, even though the heat of the brazing did somewhat deteriorate the hardness of the metal. The thickened ends suggested for the tubes were the very thing he had been waiting for, but they had not yet appeared. When he could get such thickened ends, he should be glad to use them. Meanwhile he had recourse to the reinforcement described in the paper.

The PRESIDENT proposed a vote of thanks to Mr. Osmond for his paper, and for the interesting series of specimens he had exhibited in illustration of the construction of cycles.

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Plate 48.

Scale $\frac{1}{10}^{th}$

CYCLE CONSTRUCTION.

Plate 49.

Fig. 3.

Fig. 4.

Mechanical Engineers 1897.

Fig. 5. Chain Wheel of half-inch pitch.

Scale half size.

Plate 49.

CYCLE CONSTRUCTION.

Plate 50.

Fig. 6. Reinforcement on Tube end. Full size.

Corrugated Tube.

Fig. 7. Longitudinal View.

Fig. 8. Transverse Section.

Full size.

Mechanical Engineers 1897.

CYCLE CONSTRUCTION.

Plate 51.

Joints.

CYCLE CONSTRUCTION.

Plate 52.

Chain Stays.

Fig. 15. Deformation caused by Chain Tension.

Fig. 16.

Plate 52.

CYCLE CONSTRUCTION.

Chain Adjustment.

Fig. 17.

Fig. 18.

Full size.

CYCLE CONSTRUCTION.

Plate 54.

Fig 19. *With intermediate tube.*

Multicycle Frame.

Fig 20. *Without intermediate tube.*

Scale 1/20th

Fig 21. *Back Axle.*

Full size.

CYCLE CONSTRUCTION.

Plate 55.

Fig. 22.

Tube Sections.

Fig. 23.

Fig. 24.

Full size.

Fig. 25.

Roller Chain.

Fig. 26. *Plan.*

Block Chain.

Fig. 28. *Plan.*

Fig. 27. *Elevation.*

Fig. 29. *Elevation.*

Mechanical Engineers 1897.

Full size.