THE THEORY AND CONSTRUCTION OF BALL BEARINGS.

BY W. H. HALE.

Up to the date of the advent of the modern bicycle, ball bearings had no practical application. They were scientific toys, mechanical curiosities, of admitted excellence, truly, but far too complicated and delicate for ordinary use. But when man became his own horse, the first task for his ingenuity was the devising of means for lightening his labor. And the ball bearing proved to be foremost among such means.

But the bicycle manufacturer, instead of starting with the theory and principles of ball bearings, and designing a ball bearing perfectly adapted to the bicycle, took the appliance as he found it, and placed

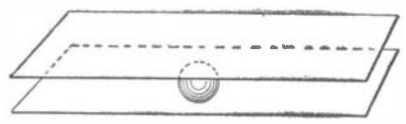

Fig. 1.—IDEAL BALL BEARING—FRICTIONLESS.

it on his bicycle, only making such changes as were absolutely necessary to make it conform to its new conditions. At the present day, twenty years and more after the advent of ball bearings into every-day mechanics, there are to be found many of the troubles and much of the construction of the earlier types.

In the opinion of the writer the most vital parts of a bicycle are its bearings. These should be constructed to run with the least possible friction under service conditions for the longest possible time with the least possible care. These may seem to be unattainable conditions, and it is granted that they are, but their approximation should be the aim of every builder of "high-grade" bicycles. The present universal test of the running qualities of a bicycle ball bearing is to raise the wheel from the floor and spin it, noting the lapse of time till it comes to rest. This is no test of the bearing under service conditions. Many makes of bicycles might be cited whose wheels spin beautifully without a load, but which weary the rider most unaccountably when ridden upon.

We have seen that the superiority of ball bearings lies in the fact that rolling friction is less than sliding. Further study of the subject will disclose the additional facts that—like wheels—balls must be proportioned to the loads they carry and the surfaces on which they travel; and it is these last two conditions, which have been overlooked or ignored, that require solution if the ball bearing is ever to come into general use. That bicycle builders do not understand the principles of ball bearings is proved by the fact that a careful observation of any considerable number of bicycle ball bearings will show that there is no uniformity in either the shape or size of the ball cups, the size or number of the balls, or the shape or angle of the cones. And as these bearings are intended to accomplish identical results, there must be either extreme elasticity in the science of ball bearing construction, or else the majority of these bearings are incorrectly designed.

To properly get at the principles of ball bearings it is necessary to go back first to the well-known advantage of sliding friction. If a man desires to move a box along a floor, he pushes it. A certain amount of force is required to do it. If he can slide it only by great effort, he places a roller under it, when he moves it with ease. This demonstrates the superiority of rolling over sliding bearings. If, now, he places another roller in contact with the first he will find that the box will move easier than when slid, but not so easily as when on one roller only, and this increase of friction is due to rubbing or sliding of the two rollers on one another; and so on. Balls can, of course, be substituted for rollers, and the result of the experiments will be the same; you will have eliminated the sliding

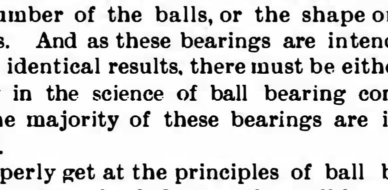

Fig. 2.—FIRST FORM OF BALL RESTRICTION.

friction between the box and the floor, but you will have added the sliding friction between the contact points of the rollers or balls.

The simplest form of ball bearing, therefore, is one ball rolling between two plane surfaces. (See Fig. 1.) Such a bearing is practically frictionless, but it is impracticable in applied mechanics. Two or more balls must be employed and they must be restricted in their path of travel. These necessities introduce two elements of friction, and it is the purpose of this paper to show how this friction may be controlled and reduced.

It will not be necessary to demonstrate that ball bearings are unsuited to plane surface motion—either continuous or reciprocal—and that they find their proper place as bearings for journals, particularly those running at high speeds. As it is necessary to retain the balls in a definite and distinct path of travel, they cannot be made to run between an inner cylinder and an outer cylindrical tube. In such a bearing they would not remain in their proper places. Some means of confinement is therefore requisite. This should be of such a character and should take such a form as to interfere as little as possible with the free rotation of the balls, and is one of our most important lines of investigation. The first method used to accomplish this confinement was to cut a curved channel in the shaft itself within which the balls rotated. (Fig. 2.) Then as means of adjustment for wear were found necessary, the outer track of the balls was also made a channel, but divided in the center, directly in the path of the balls, and the two halves made to advance toward or retreat from one another by means of screw threads cut upon them. Bearings of this character are still in use, although originally designed more than twenty years ago, and this survival is not due to remarkable excellence of design, but to the conservatism of the users. This form of bearing has not only the friction of the balls against each other, but also that of the balls against the sides of the channels.

The first departure from this method consisted in making the channels V instead of U-shaped, in order to make the path of the balls a line instead of a curved surface. To some extent this was an improvement, but it introduced a twisting friction between the balls and their tracks and increased rubbing between the balls themselves, owing to their not rolling on the ends of their vertical diameters. Some of this style of bearings are still in use.

When the present type of bicycle came into existence it became possible to discard the single form of ball bearings and to construct a double one, and it is this type which is now universally used and which invites our attention in this discussion. Typically, these are all alike. They consist of a circular ball cup, with a flat back, forming two points of contact for each ball. These cups are placed at opposite ends of the shaft with their backs toward each other, while outside of them and encircling the shaft are two hollow truncated cones bearing against the balls, their smaller diameters being in contact with or underneath the balls them-

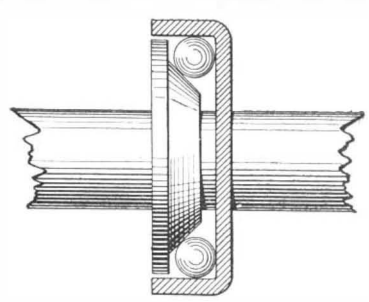

Fig. 3.—SECTION THROUGH ORDINARY BALL BEARING.

selves. Some forms of ball bearings reverse this, placing the cones inside and the ball cups outside, but the type remains the same. This is practically the ball bearing as we know it to-day.

In this form of bearing the balls revolve on three different diameters, varying according to the positions of the three points of contact. They cannot, therefore, obtain perfect rotation in any one plane and must have some sliding friction at all points as well as the friction upon each other. The bearing surface of the shaft can be neither a cylinder nor a disk, for these would be unadjustable; it must therefore be a cone. In the construction of these cones all sorts of arbitrary angles are used, each maker evidently having one of his own which he believes to be—or at least claims to be—the only correct one. The most common angle is 45°, although there are many bicycle builders who could not tell you the angle of the cones they use, and who would not think the matter of any consequence if they could.

The correct angle for a cone should be such as to allow the greatest possible freedom of rotation to the ball and avoid unnecessary wedging and crowding. That of 45° is clearly wrong, for it presents the three most widely separated paths of rotation possible, and therefore causes the greatest amount of twist. What is the best angle then, and how shall we find it? It is evident that it must be less than 45° for even that angle exerts too great a pressure against the back of the ball cup.

If we take a sectional sketch of a ball cup containing balls and draw two lines through the contact points of ball and case of two opposite balls, we shall find these lines to intersect in the center of the shaft at a distance back of the center of the balls equal to one-half the diameter of the ball case. If from this point lines be drawn touching the inner surfaces of these opposite balls a cone is formed whose apex is the center of the prolongation of the axis of rotation of the balls, and whose surface is such as to continuously maintain the balls in this rotation. In addition this cone is governed and determined by the number and size of the balls in the case, size and configuration of the case itself, and the path of the balls.

Another detail that has received far less attention than it deserves is the size and number of the balls used. Quarter inch was the original bicycle size, but a few years ago it was found that larger sizes were better. They did not break nor split so readily, did not roughen up, they did not jam, and they did not wear the cones and cups so rapidly. The 5/16" was better than the ¼", and the ⅜" better than the 5/16". These were facts easily proved by demonstration, and the bicycle builder accepted them as such and took advantage of them. He did not seek the cause for the

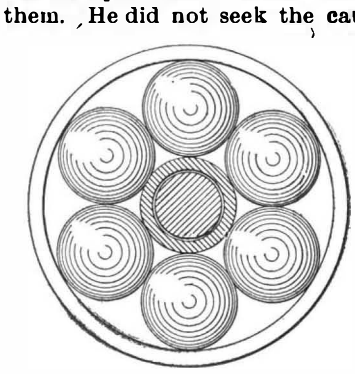

Fig. 4.—FRONT VIEW OF 6-BALL BEARING.

improvement, nor did he try to ascertain how far the improvement would continue.

It remains then for the theorist, the experimenter, to take up this good enough improvement and learn the cause of its superiority, as well as to reason out the possibility of continued improvements up to the logical or practical limit. The question is: If the larger ball makes the better bearing, why does it do so and how long will increase in size continue the improvement?

With a given ball cup and a given size of shaft the largest balls that can be put into the case will have a diameter equal to one-half the difference between the diameters of the shaft and ball cup. But this size of ball could not be used, since there would be no room for the bearing cone, and hence no chance for adjustment. Six is the best and presents the well-known symmetrical appearance of a circumscribed hexagon, and the cone becomes of usable size. Here, too, we note a marked peculiarity; the balls and their bearing cone are approximately the same size.

Experience has shown that too small balls break up in service, and larger balls have been employed until, at the present day, from seven to ten are the numbers generally selected. Decrease in number and increase in size has invariably resulted in improved bearings, but as before stated there has been little or no serious attempt made to ascertain the limit. With every increase in size of ball there is a decrease in the size of the cone until, with six balls, as we have seen, the bearing diameter of the cone and the diameter of the balls are practically the same. This suggests as the logical limit of improvement the point where the wearing diameter of the cone equals the diameter of the balls used.

In designing a ball bearing for general purposes, therefore, which shall embody the principles above presented, the first thing to do is to ascertain the maximum load. This will determine the size of the axle that may be used. As upon this axle is to be placed the hardened cone which serves as the inner bearing for the balls, the thickness of such a cone must be added to the diameter of the axle in order to determine the proper size for the balls. And the diameter of the cone at this bearing point plus twice the diameter of one of the balls used will be the inner diameter of the required ball cup.

If the six ball bearings be adopted, and supposing

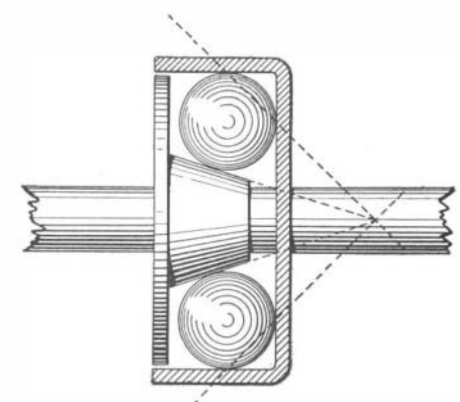

Fig. 5.—SECTION THROUGH 6-BALL BEARING, SHOWING METHOD OF MEASURING ANGLE OF CONE.

that we have found a three-quarter inch axle to be sufficient, the allowance of an eighth of an inch on each side for the bearing cone will be ample, when it is evident that we shall need six one-inch balls for the bearing and that the outer ball cup will have an inside diameter of three inches. It may be argued that this will make a clumsy bearing, that smaller balls will make a smaller cup and give a neater effect. To this it may be answered that clumsiness is merely the point of view. The present pneumatic tire was clumsy when it first appeared; now the absence of it would be clumsy. Ball bearings to be generally successful must be practical, and to be practical all sentimental regard for appearances must be cast to the winds and such a bearing devised as will best fulfill all the demands that may be placed upon it.

TYPICAL PERPETUAL MOTION FRAUD.

By the courtesy of a correspondent in Bradford, Pennsylvania, we are enabled to present illustrations of one of the neatest perpetual motion frauds that ever drew money from a credulous public or gained for its author a well earned seclusion within the walls of a State prison. Some two years ago, one J. M. Aldrich exhibited to certain citizens of Bradford "a machine which he called a motor," and on the strength of its unique performances secured several not inconsiderable sums of money from the favored few who were permitted as "parties of the second part" to secure an interest in the invention. Subsequent irregularities in the conduct of the "party of the first part" in these transactions, and a too liberal discrepancy between the promise and performance of the "motor," led to the arrest of Mr. Aldrich and his detention for three or four months in the county jail. Unfortunately for the general public, the Bradford victims feared that they did not have sufficient evidence to secure a conviction, and he was released. "Motor" promotion must have proved a lucrative calling, for, notwithstanding his peep through the open doors of the penitentiary, Aldrich cast his net for fresh victims, and for two years continued, no doubt, to prosper after the manner of his kind. Last March, however, one of his many "half interest" holders secured the model and sent it to the Patent Office, where the perpetual motion was traced to its time-honored source—a concealed spring.

We can conceive it is quite possible that the builder of this "perpetual motion machine" did not set out with any deliberate intention to deceive the public. Like many another, before and since, he was doubtless attracted by this will o' the wisp of the inventor, and started with the honest intention and expectation of building a machine which would run without the assistance of any external agency. The type of motor aimed at was one in which the force of gravity should supply the motive power, and it took the form of a rotating shaft, two transverse arms placed at right angles to each other, and jointed levers which should always present an excess of turning moment on one side of the shaft. As will be seen from our engravings of the machine, disk-shaped weights are carried at the outer ends of two transverse arms which are themselves carried at opposite ends of the main shaft. The weights are adjusted at the ends of swinging arms which are capable of motion through an arc of 90°. The direction of rotation (see smaller engraving) is the same as that of the hands of a clock, and the weighted levers are so attached to the transverse arms that in the downward half of each revolution they fall outward and forward, thus lengthening the radius on which they travel relatively to the center of the main shaft. On the upward half of the revolution, the weighted levers close up and the weights themselves describe an arc of rotation with a smaller radius relative to the shaft. To assist in giving a preponderance of turning moment on the downward half of the revolution, the transverse arms are split in the center and are capable of sliding bodily across the main shaft, as will be clearly seen from the cut. As each transverse arm with its jointed lever and weight rises a little past the horizontal it slides forward and downward, thus throwing the weight on the opposite end of the arm still further from the center and increasing the turning moment on that side, at the same time decreasing the moment on the upward half of the revolution. The transverse arms are kept in place by means of small rocking levers which extend from steadying arms attached to the shaft.

To provide against too rapid motion of the machine and a too prodigal display of its powers, a centrifugal governor is provided near one of the vertical posts which carry the main shaft, and its superabundant energy may also be controlled by a small brake which acts on a flywheel attached to the center of the shaft and is held against the wheel by means of a rubber band.

Now we have no doubt whatever that Mr. Aldrich believed that his extensible arms with the weights flung far out on one side of the shaft and drawn snugly in on the other side, would not only insure perpetual rotation, but in a machine of sufficient size would exert a not inconsiderable number of horse power. As a matter of fact, even in a frictionless machine, there would be no turning moment whatever, and as it was, Mr. Aldrich found that on starting his machine it was very quickly brought to rest by the energy consumed in overcoming the internal friction.

If he had been content, as many another unfortunate had been before him, to consign his machine to the scrap heap, it would have been better for him and for his victims; but being of an ingenious and resourceful mind, and doubtless "tempted of the devil," he conceived the idea of overcoming the troublesome friction by means of concealed clockwork, and acting upon the thought he carefully carved and whittled out the wooden bed plate of the machine and placed therein the springs and the train of gears shown in the illustrations.

The gears were connected with the main shaft by means of a small rod extending through the right hand post, a couple of bevel wheels at the top of the post serving to transmit the motion to the revolving shaft and weights. The model, as it stands on our office table, is certainly a masterpiece of deception, and eminently calculated to deceive the unwary. The problem of concealing the joint, after the "works" had been inserted in the hollowed out base of the machine, was solved by forming a bevel joint and making it coincident with the bottom edge of the base, as shown in our drawing. This has been done so skillfully as positively to defy detection, and the illusion is further assisted by the extreme roughness with which the other joints on the machine have been finished. By pushing the little block, which carries a brake, to one side, it may be lifted away, exposing two openings in the base for winding the springs. Considering the artistic clumsiness with which the whole affair is put together, the worm holes neatly drilled, but drilled with that careless abandon which marks the ravages of the native worm, the coarse, rough jointing of the posts standing in close proximity to the exquisitely finished bevel joints of the base, one cannot but regret that the unquestioned dexterity of the inventor was not directed to a better end.

With perpetual motion so palpably accomplished, however, Mr. Aldrich saw in his creation a means of immediate if unlawful gain. Hence, three things followed: Many simple people were relieved of their money; Aldrich was given space for repentance within Auburn prison; and the SCIENTIFIC AMERICAN is enabled to "point a moral and adorn a tale," for the benefit of the all too easily snared investor.

The Feather-Work of Hawaii.

It is seldom that the native products of the savage or semi-savage races are at all remarkable for artistic beauty, no matter how curious or interesting they may be. Among such products the magnificent feather-work formerly produced by the natives of the Hawaiian Islands may be assigned a very high place. This work consisted of feather plumes, feather-covered helmets and dance masks, of wreaths and tippets, above all, of gorgeous cloaks, covered with feathers of brightly-colored native birds. All the earlier visitors of the Hawaiian Islands mention the feather-work. Mr. Miller Christy, F.L.S., has recently written an interesting article entitled "The Rare Feather-Work of Hawaii," in the English Windsor Magazine, and we obtain our facts from this source.

Although once fairly abundant in Hawaii, specimens of this splendid feather-work are now very scarce and more highly prized than ever, for not only has the art of making it been lost, but the bird whose feathers were most highly prized in the manufacture has become extinct. The making of cloaks and other feather-covered articles of dress or ornament dates doubtless from a very remote period in the history of the islands. In bygone days it was the principal occupation of the wives and daughters of Hawaiian nobles, and the ancient kings had a regular corps of skilled feather hunters who were very expert in their business. In catching the birds, a net or snare was sometimes used, but more often a kind of birdlime made from the sticky juice of the bread-fruit tree was used. This was smeared on the higher branches of the trees frequented by the birds or on long poles set up for the purpose of catching them. Often a live specimen of a brilliant scarlet bird known as the "iiwi" was fastened in the vicinity to act as a snare. It is said that the hunters sometimes transplanted trees to the heart of the forest in order to excite the birds' curiosity. The old bird-catchers were doubtless important men in the community, for feathers were considered to exceed in value any other kind of personal property. The difficulty of obtaining sufficient feathers for the manufacture of a cloak must have been enormous, so that it is little wonder that the cloaks are of such value. The ground-work of all the feather articles is coarse netting made of string manufactured from the fiber of a native grass. The outer side is alone covered with feathers, the shafts of which are so dexterously and closely woven into or sewn onto the fabric of the net that the feathers which overlap one another present a surface as smooth and glossy as the back of a live bird. Among the birds which provided the feathers were the mamo-bird and the oo-bird, also the iiwi-bird and the ou-bird. The cloaks already mentioned were by far the most striking products of the Hawaiian feather-workers. They have been spoken of as "royal cloaks," but only those made solely from the brilliant orange-hued feathers of the now extinct mamo-bird can be properly so described.

The right to wear cloaks made from the feathers of this royal bird was the exclusive prerogative of the king. To all others yellow was in the native language "tabu," whence comes our word "tabooed." One of the yellow cloaks which was worn with a helmet of the same color must have formed a garb of truly royal magnificence. Only one or two of such cloaks are known to have been made. The great state robe and war cloak of the king Kamehameha I. was made up from the smaller tippets of the inferior chiefs; it is 56½ inches in length down the back and 12 feet 4 inches in circumference around the skirt. It is said to have continued to increase in size through eight preceding reigns as each successive monarch added something to its size. With the exception of a very narrow border of red feathers it is wholly of the brilliant yellow feathers of the now extinct mamo-birds. The "mamos" worn by chiefs were covered with feathers of commoner birds, chiefly red and yellow, but the yellow is that of the oo-bird and not of the mamo-bird. The two colors are usually arranged in a simple curved or angular pattern showing considerable poverty of design. The length of the cloaks worn by the chiefs was an indication of their rank.

It is difficult to gain anything but an approximate idea of the number of birds required to make one of these garments. In the case of the royal cloaks the feathers of ten birds would on an average be required for each square inch. By simple computation it will be seen that 20,000 to 30,000 birds will be required to make a royal cloak, so that it is little wonder that one cost $100,000.

Next to the cloaks the most remarkable feather-covered objects produced were large helmets that somewhat resembled those of the ancient Greeks. The frame is of wickerwork over which is stretched a feather covered network. Less remarkable, but equally imposing, were the long-handled feather plumes which were borne by the king and his highest chiefs as insignia of rank and banners in war. These plumes also marked the temporary stopping place of the king or leader. Other feather-covered objects manufactured were dance masks, which consisted of huge heads constructed on a wicker-covered frame and having superlatively hideous features; the mouth stretching from ear to ear, armed with several rows of sharks' teeth and great goggling eyes of mother-of-pearl. As late as 1888 two native nobles wore their "mamos" at the opening of the Hawaiian legislature. When the Hawaiians adopted the dress of civilization, the monarchs, however, still continued to wear the royal mamo at their coronations. Naturally the finest series of Hawaiian featherwork are still to be found in Hawaii, principally in the Bishop Museum at Honolulu.

Automobile News.

In addition to international yacht racing for a cup, we shall now have international automobile races for a cup. The Automobile Club de France will have the keeping of the cup, which can be challenged for by any club in any country, in the name of one of its members. The first contest is to be held in France, and if the French vehicles are beaten, in the country of the winning club. The name, date, and distance of the first race will be decided later.

It is announced that there will be another New York-Irvington automobile race in a few weeks, under practically the same auspices as the race held in 1896. The management of the former race was very much criticised, and it is to be hoped that the shortcomings of those who have the matter in charge will be less in evidence.

Boston, Chicago, and New York will each have their automobile clubs. Some of them are in the initial stage of organization, but they all promise to be successful.

A "stable" of gasoline vehicles has been opened in New York, on West Forty-eighth Street.

Mr. Whitney Lyon drove his Riker electric dos-a-dos trap from New York to Coney Island a few days ago. He covered the round trip of thirty-five miles without recharging the batteries. There were four persons in the trap during the trip. The time from the ferry at Broadway, Brooklyn, to the beach was forty-five minutes. Although the trap was not supposed to cover more than twenty-five miles without a renewal of the charge, there was ample power at the end of the trip.

Home-Made Migranine.

In preparing migranine at home, C. Weinedel proposes to make an admixture of 0·5 to 1·0 of burnt magnesia, in melting the ingredients, i. e., antipyrine 85 grammes, caffeine 9 grammes, and citric acid 6 grammes, whereby the preparation is prevented from getting damp, if the melting temperature had been a low one, which always gives a white product. Even by a mere mixing with admixture of magnesia, a rather stable migranine can be produced.—Apotheker Zeitung.

SCORES of prominent people in Washington have taken to cycling this season. Recent converts to the chainless idea include Senators Wolcott and Chandler; Captain Sigsbee, late commander of the ill-fated "Maine;" Assistant Secretary of the Navy Allen, and Rev. Drs. Hamlin and Mackay-Smith.