THE MECHANICAL DESIGN OF BALL BEARINGS AND ROLLER BEARINGS.*

By W. S. ROGERS.

THE first important thing to know about ball bearings or roller bearings is the material to be chosen. This question can be decided only after one knows where the bearing is to be used, the revolutions per minute, the maximum load, whether the load is constant or intermittent, and the care the bearing will receive in service.

The balls should be of the best quality in all cases. In selecting them the reputation of the ball maker is

FIG. 1.—GRAPHIC FORMULA FOR DIAMETERS AND LOADS

the only guide, as the largest manufacturer does not always make the best balls, neither is the highest-priced ball always the best. I have found from experience that hot-forged balls are the strongest, provided the maker has used the best grade of steel for the purpose. The honesty of the ball maker must be depended upon for this.

The balls should be accurate. This the user can determine by measuring them for himself. Knowing that perfect accuracy cannot always be obtained, I have always used the formula shown in Fig. 1.

The material for the housings, or shells, sleeves, rings, races, or cones, as they may be called (for the nomenclature of ball or roller bearings has no standard) must be determined by the conditions. Jessop's tool steel may be suitable in one condition, uncalled for in another, and totally unfit for the duty in still other conditions, and the same may be said of every known brand of steel. Practical knowledge of past performances is the only safe guide. Laboratory trials under refined atmosphere prove very, very little.

Assuming, then, that we have the best of materials obtainable for ball bearings, the question is, What is

FIG. 2.—RADIAL BEARING.

the best form of bearing? But before going into the problem, let us see what the ball has to do in the various types of bearings.

There are but two original purposes of bearings, consequently there are but two original types. One type serves for carrying the load directly upon and at right angles to the shaft or axle. This is termed a "radial" bearing. The other type takes the load of the shaft or axle endwise, or parallel to it, and is termed a "thrust" bearing.

Fig. 2 shows a radial bearing carrying a load upon the shaft. It is plain to see that the axis of rotation of the ball is parallel to the shaft and at right angles to the direction of load and resistance. With proper design and good materials, such a bearing will last a long time and save friction.

Fig. 3 illustrates the simplest form of thrust bearing, in which we note that the axis of rotation of the ball is at a right angle to the shaft and parallel to the direction of load and resistance.

Thus, we see that the natural ball actions in the two fundamental types of ball bearings are in direct conflict with each other, and that it is contrary to the established laws of mechanics for a ball to have more

FIG. 6.

FIG. 7.

than one axis of rotation at the same time without adding a friction and resistance of its own which eventually destroys itself as is shown in Fig. 4.

Here we have the radial bearing with its rotation of $A A$ used in combination with the thrust bearing having its rotation of axis $B B$ —one ball used to perform two functions diametrically opposed. Simply impossible and absurd on the face of it! The result is that

the ball wears out of round, cuts grooves in the contact surfaces, and eventually crumbles away or breaks, ultimately destroying the entire bearing. But this is not bad enough, and we have another invention shown in Fig. 5.

Here we have the opposing plates of load and resistance joined together. Not satisfied with trying to

FIG. 4.

FIG. 5.

make the ball turn two ways at once, the two resisting plates are united to prevent their eliminating the error existing in rolling contact, and compelling the ball to grind itself and the plates away faster. A modification of this type is found in Fig. 6, but still possessing all its evil features.

The good point which this type has to recommend it is that it can be "adjusted" and the wear taken up, but as we only know the time for adjusting has arrived when the bearing has crumbled away, the recommendation in its favor possesses little value.

The next modification of the inventor in his efforts to make a sphere rotate on two axes at the same time is found in Fig. 7.

Here we have the three-point bearing. It is adjustable and the designer has eliminated one rubbing surface and "it spins like a top." But he has forgotten or else does not know that the top has but one axis of rotation and that when he removed one contact surface he left the resistance to be distributed between the other three points.

Then we have another effort in the attempt to make two conflicting laws into one illustrated in Fig. 8. This

FIG. 3.—THRUST BEARING.

form is not new; it was developed over twenty years ago, but has become fashionable in the past two years. For use as a bearing to carry a radial load only, this type is all right and will last indefinitely if properly lubricated and cared for; but its advocates are forcing it into use both as a radial and thrust bearing, much to the sorrow and expense of the buyers and users, who assume that the sellers of an article are experienced in all points relating to their business.

Some years ago a form of thrust bearing illustrated by Fig. 9 was brought before the machinery world and great things promised for it, but it quickly proved worthless, although I very much doubt if the mechanical reasons for its failure are yet clear to those most interested.

As the figure shows at once, it was of the four-point contact form, one grooved collar being tight upon the shaft and free from contact with the pulley, the other collar being free from the shaft and tight in the pulley; but it was the same effort to make a ball go in two axial directions at once. This form of bearing is good for thrust purposes only, and at very low speed has been successfully used for many years, its only error being in the angles of contact of 90 degrees.

Forty years ago the forms of ball bearings were

FIG. 8.

bore and the outside diameters as well as true with the sides.

It will carry as much load as a two-point bearing if true and accurate. For this reason the two-point is more popular, as it is much easier to make and at a better profit. This type of bearing can be made adjustable, but should not be used for carrying end-thrust loads.

The most surprising design of a combination radial and thrust bearing ever inflicted upon a bewildered mechanical community is that shown in Fig. 11.

The rollers have round ends, but are sometimes made with a sharp bevel and are held in a cage or retainer. The desire of the rollers under duty is to twist themselves in two, and failing in this they distort the cage and quickly destroy everything. Innocent automobile buyers have suffered greatly from this type owing to its cheapness.

FIG. 9.

Fig. 12 illustrates another form of design of both ball and roller bearings that inventors and promoters have spasmodically tried to introduce for the past thirty years. A small ball or roller is interposed between the large ones carrying the load, with the assumed idea that the smaller ball eliminates the friction of the surfaces of the larger ones produced by their rolling in opposite directions. The fact of the matter is the balls or rollers are never in contact when under load in the design, as shown in Fig. 13. The weak point in the type shown in Fig. 12 is the high speed of the smaller ball or roller which rapidly destroys its usefulness.

Sometimes the question is asked, how much friction is caused by a retainer or cage used to guide and keep the balls or rollers in place, and it can be answered by saying that such friction is infinitesimal and not worth taking into account. The chief thing to con-

FIG. 10.

sider is the elimination of unnatural friction and work for the balls or rollers.

Fig. 14 shows another freak in the form of a "ball end-thrust roller bearing." When first exploited it was as a bearing to take the end thrust as well as direct load. The proposition was too ridiculous for the mechanical public, and the "end-thrust" part of it is in the dim past. A is the roller; $B B$ are balls socketed into either the roller or the cage end, C —or both, as fancy pleases. The balls act simply as gudgeons—noth-

* The Engineering Magazine.

ing more. Were the ends of the roller rounded or made to conform to the shape of the ball the same result would be accomplished at much less expense. Nevertheless, it is a good roller bearing.

A form of bearing for carrying the direct radial load and at the same time assuming some of the end thrust is the conical roller type. The circles of rolling contact are not all true and it is not the perfect friction-

forever." Few are in demand, as the first cost is too great for the weight of the bearing commercially.

Bearings of this form have been taking end-thrust load and running 12,000 revolutions per minute for the past seven years, every day in the year. They are also practically noiseless if the angles are correct. Care must be observed in making them to have the angles of contact a true rolling surface with the cross section

there that control the manufacture of thrust bearings?" There are no "controlling" patents of any kind whatever, and it is either rankest idiocy or else blackmail for any one to claim or threaten such things. The original ball thrust bearing with balls held in a cage between two hard, flat surfaces was granted in 1873. The type shown in Fig. 17 was patented first in the seventies and has been duplicated since several times owing to inefficiency of American patent-office methods.

Nearly seventeen hundred patents have been granted since 1833 upon roller and ball bearings. The original one was an application to a grindstone. As I have

FIG. 11.

FIG. 17.

less bearing many of its advocates claim; nevertheless it is a happy medium between an easy roll and a wedge, and will endure greater abuse than perhaps any other type or form. There have been many forms of this design shown in Fig. 15. What is the correct pitch or angle of rotation of the rollers with reference to the shaft is unknown, as no comparative trials have ever been made.

A roller bearing with long cylindrical rollers should be avoided always. The frequent inaccuracy in grinding the rollers so as to preserve the same diameters at the ends and in the middle prevents an even, true rolling motion under load. The tendency of one end of a roller to travel faster than the other end starts the cage or retainer to winding or twisting, and the whole fabric becomes worthless. Rollers should never be made more than 4 inches long, and then only when $\frac{3}{4}$ inch in diameter or larger. Even when no cage is used this tendency of the rollers to ride out of parallel to the shaft is apparent. For this reason there should always be allowance given between the outside shell and inner sleeve of plenty of play for readjustment of the rollers unless they have come to the side of the shaft where they are free from load.

The same reasons exist for making ball bearings "easy fits" or what we might term "shaky" when assembled. The most worthless bearing made is that which is assembled by force.

The thrust bearing shown in Fig. 3 is the most popular because of its ease to make. It is durable as well,

of a cone produced by correct included angles from the center of the shaft. These angles must also be concentric with each other, and with the inner diameter of the collars as well. For high rotative speed it is essential that the bearing be as nearly balanced as possible.

Fig. 18 illustrates what engineers would term a "makeshift" thrust roller bearing, suitable only in contracted and narrow spaces where the load is greater than a ball bearing of the same size would sustain.

On can readily see that it is not right; the circular motion of the cage or carrier of the rollers is shown by the arrow *a*. The determination of the rollers is to travel tangent to *a* as shown by the arrow *b*, causing constant slipping and resistance. But it is about 25 per cent better than none whatever, and works quite a long time at slow speed and has been before the public for about thirty years. I am often asked if this type of bearing cannot be made in halves, and my answer is, "No"—because the action of the rollers when passing over the joints of the hardened steel collars is the same as that of heavy car trucks upon railroad track joints—only worse, as the steel collar joints are very brittle and the chips soon cause the rollers to clog and slide.

FIG. 15.

stated, the mass of existing patents to-day are not worth the paper they are printed upon except as "promoters' assets." Nevertheless, the industry is but an infant, growing, and yet in its knickerbockers.

GYPSUM (PLASTER OF PARIS) AND ITS UTILIZATION.—I.

AMONG the materials with which nature has so abundantly endowed us, gypsum, notably the gypseous rock, the anhydrite from which it originated, alabaster, holds by no means the least important place, and the immense masses in which this mineral occurs, must have led at an early period to its employment and utilization, while the efforts to make these valuable deposits serviceable to man, have extended the circle of

FIG. 18.

FIG. 12.

FIG. 13.

notwithstanding the eventual loss of spherical shape of the balls on account of the effort exercised by the two opposing collars to drive the balls on two different rotating axes at the same time. In addition to the motion shown in the illustration the ball is compelled to travel in a circle *a'* right angles to its axis. This causes slight wearing friction. At speeds over 400 revolutions per minute there is also a tendency on the part of the balls to fly outward and cut their way out of the cage or retainer. This they eventually do, and to overcome this the bearing shown in Fig. 16 is used. It is simply a two-point bearing, the balls rolling in grooves. They may be held in a retainer, or not; it is immaterial. The cage is simply for convenience in handling. This type of bearing may also be made with but one grooved collar. When the two grooves are used care must be taken to see that the ball races are concentric with each other and with the inner diameters when they are to be used upon a shaft.

FIG. 14.

Another type of end thrust sometimes called a four-point bearing has been shown in Fig. 9. This is rather an expensive bearing unless used at slow speed and for heavy loads.

The correct thrust bearing in point of durability at extremely high speed, and as a load carrier, is seen in Fig. 17. This is the true, rolling four-point thrust bearing—hard to make—but when once made accurately and of good material, it is a "beauty and joy

The best form of end-thrust roller bearing is that shown in Fig. 19. To be perfect in every way there should be an additional end-thrust bearing on the outer end of each conical roller. This makes a very expensive bearing when completed, but it will withstand great loads at very high rotative speed.

In this article I have said but little concerning the cages, retainers, or carriers for holding the balls or rollers in place, for the reason that their name is legion and after all is said and done there has been nothing new developed or patented in the past twenty years that had not been anticipated by mechanics and inventors in years gone by. Recent court decisions have proven that patents obtained within the past eighteen years are, to all commercial intents, worthless.

I am asked how close a fit should the collars of a thrust bearing be to the shaft, and I say, 0.01 inch, not less.

The man who advocates less knows nothing of expansion or contraction, and is close kin to the crank

FIG. 16.

that spends hours of valuable time every day trying to part his hair absolutely in the middle.

I am often asked, "How long will a bearing last?" It all depends upon where it is used, how it is used, its design, and who made it.

The same question and answer applies equally as well to emery wheels, steel rails, and beer. The biggest brewery does not always make the best beer.

Another query oft repeated is: "What patents are

its utility until, as a matter of fact, gypsum has become one of the most extensively used substances.

In the very earliest times people were familiar with gypsum or plaster and knew very well how to use it. We hear first of its use through Herodotus, who found the ancient Ethiopians employing it, after it had been burned, for coating the dried bodies of their deceased relatives, creating thereby a solid body, in human form, which, after it had hardened, they painted in colors, and in this condition handed it down to posterity. The Egyptians of old used gypsum for mortar and the great Pyramid of Cheops is built with mortar consisting of 83 per cent of gypsum. In other writings, reference is made to gypsum, or plaster; thus Pliny and Vitruvius refer to its use in building operations as a cement, but more especially to its employment for the stucco work that was so extensively practised in the olden times.

Pliny, moreover, informs us that Sysistrates, of Sykion, being acquainted with the property plaster pos-

FIG. 19.

sessed of assuming any form given to it and then hardening, made use of it in the production of casts; he was the first to take a cast of a human face in plaster and pour wax into the mold, whereby he obtained a reproduction, perfectly true to nature, that could be utilized for various other purposes. Gypsum powder was used for scattering over the floor by the circus performers in the arena, and later, the transparent, colorless gypsum, or selenite, was adopted by the early