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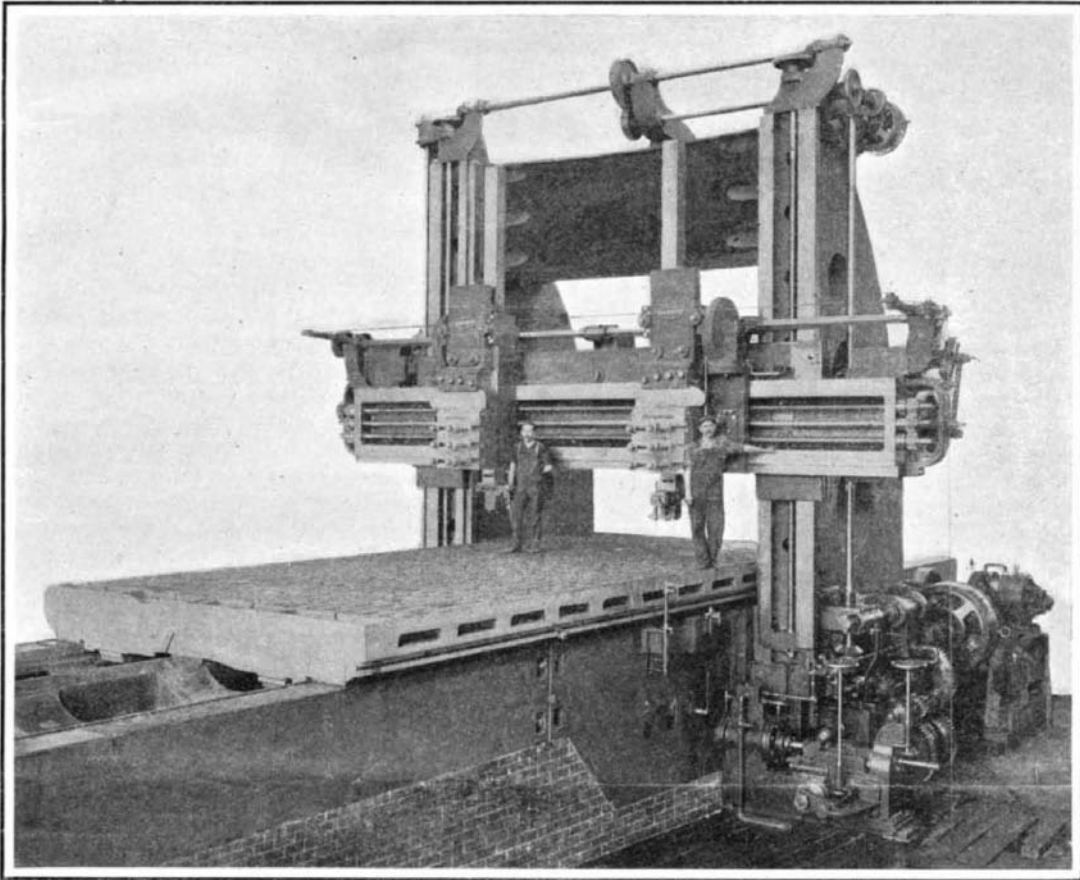


FIG. 1.—A GIGANTIC PLANER. WEIGHT 845,000 POUNDS. 207½ HORSE-POWER DEVELOPED BY FOUR MOTORS. NEW MOVEMENTS HAVE BEEN ADDED TO THOSE OF THE STANDARD MACHINE.

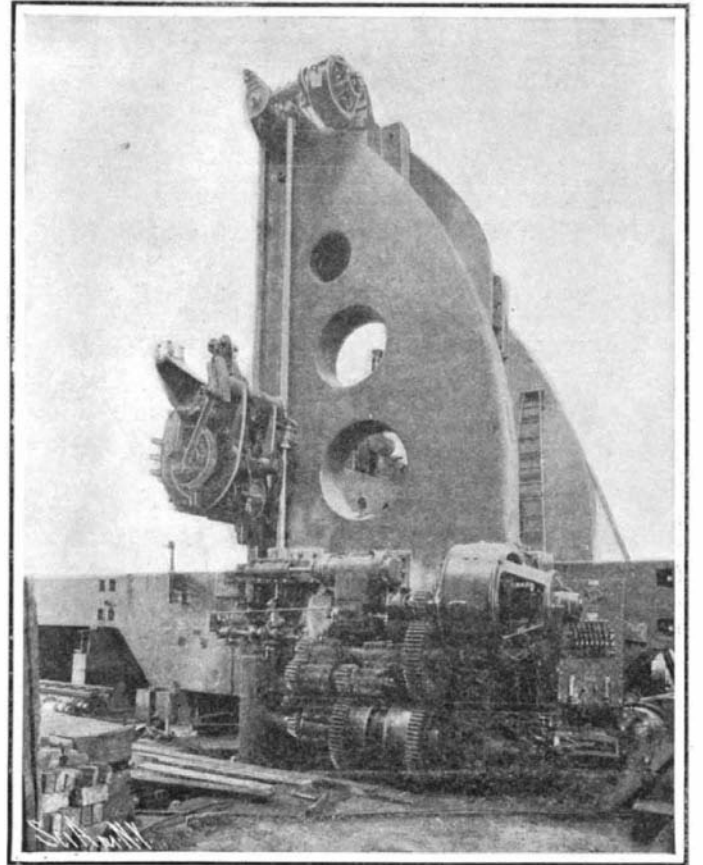


FIG. 2.—MAIN DRIVE BY 100-HORSE-POWER MOTOR THROUGH GEARING AND PNEUMATIC CLUTCHES.

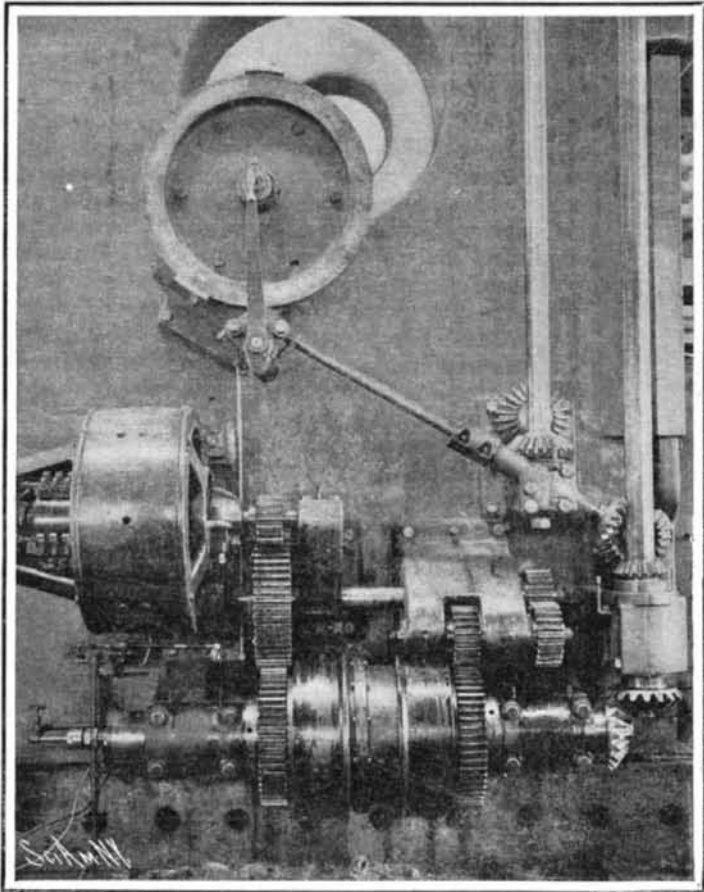


FIG. 5.—SLOTTER DRIVE SITUATED AT BASE OF LEFT-HAND UPRIGHT.

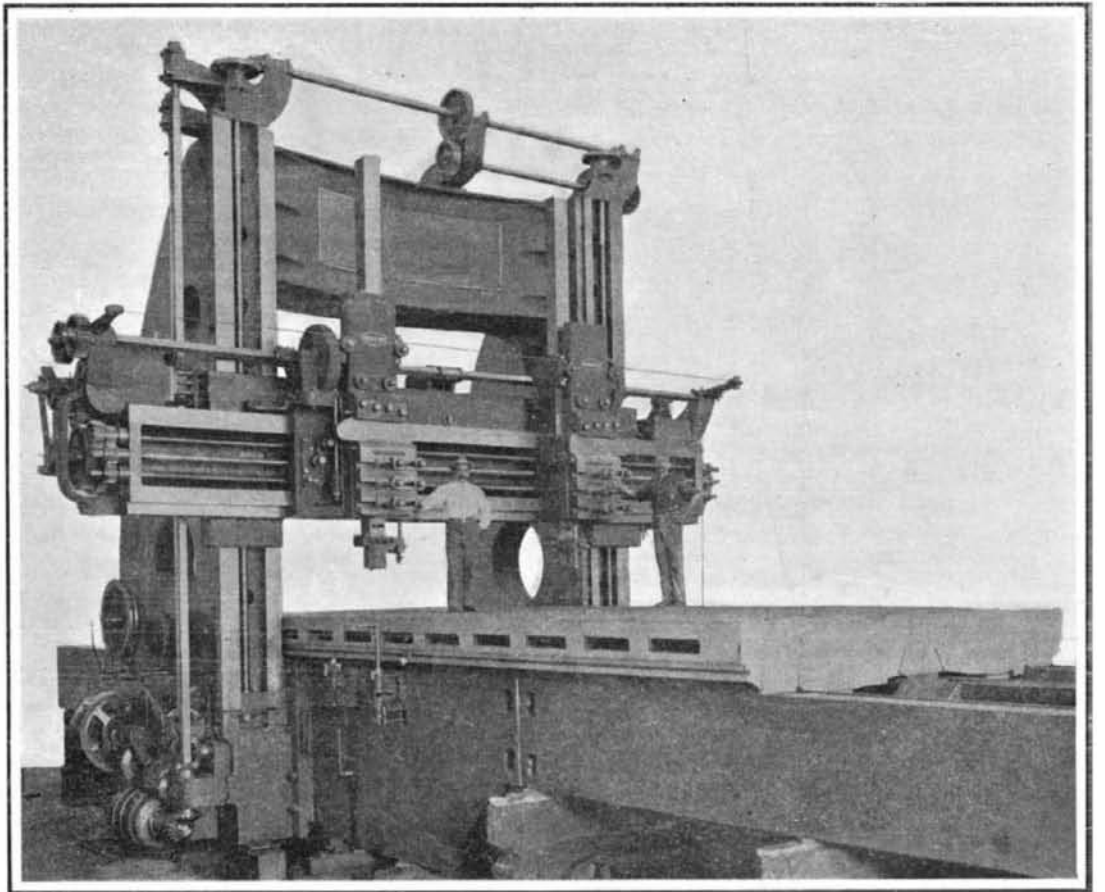


FIG. 6.—LEFT-HAND SIDE WITH MOTOR FOR SLOTTER BAR DRIVE AND PNEUMATIC CLUTCHES FOR SAME.

THE BIGGEST MACHINE OF ITS KIND EVER MADE.—[SEE PAGE 9.]

# ELIMINATION OF FRICTION IN BALL BEARINGS.\*

IMPORTANCE OF THIS QUESTION IN VIEW OF THE APPLICATION OF SUCH BEARINGS IN HEAVY WORK; SOURCES OF FRICTION ANALYZED.

BY J. F. SPRINGER.

THE elimination of friction from bearings in general is one of the most important topics that can engage the attention of the mechanical engineer. There are three main reasons for this: First, friction means abrasion of material, and the removal of material through abrasion is a very great disadvantage, inasmuch as it results in change of form and dimensions of the contacting parts, thus limiting their life. This

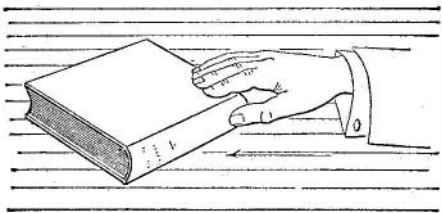


FIG. 1

is what we term "wear and tear." Second, the wearing away of this material requires power, and this power is worse than lost. And in the third place, friction sets up heat, which alone is often a most serious detriment.

Friction is of two kinds—*sliding friction* and *rolling friction*. Given two surfaces in contact, if there is such motion of one relatively to the other that the motion is parallel to the contacting surfaces, the result is sliding friction. Thus, as in Fig. 1, a book pushed across the surface of a table gives an example of sliding friction. And, furthermore, it is immaterial whether the book is pushed in a "right" line. Indeed (Fig. 2) it may be rotated so that every point of the surface of the book contacting with the table surface,

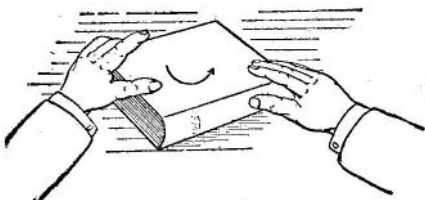


FIG. 2

except the center of rotation, moves in a circle, yet sliding friction results if these circles are in a plane parallel to the surface of the table. Such friction arises, of course, because the contacting surfaces are not absolutely smooth and so present to each other irregularities which mutually engage. When motion occurs under pressure these mutually engaging projections tend to abrade each other (Fig. 3). This is because the pressure, in proportion to its amount,

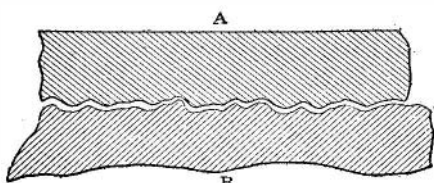


FIG. 3

tends to maintain the interlock. As stated, the removal of the particles is wear, requires power, and sets up heat. Thus is to be explained the excessive wear, loss of power, and rise of temperature which occur in the ordinary plain bearing.

However, the motion may not be in a direction parallel to the contacting surfaces, but may be such that there is an introduction and withdrawal of small projections, and this constitutes a form of rolling friction.

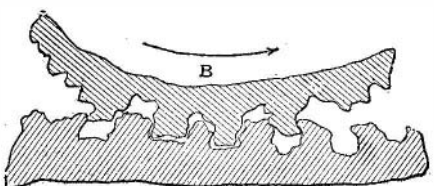


FIG. 4

It is due to the fact that the contacting surfaces are not absolutely smooth, but present to each other slight protuberances and depressions at a time when contact is maintained under pressure (see Fig. 4), as is the case with a wheel. Then there is the continual presentation of limited contact, combined with pressure, whether that which rolls is a ball or a roller. If the particles in actual contact are not adequately supported

by others in their vicinity, small particles are detached from both contacting surfaces by a crushing process. Hardness combined with toughness (which is now possible to secure) goes far to eliminate this particular result of rolling friction. But the difference between sliding and rolling friction, as to abrading result, is well known to be very great. Indeed, a

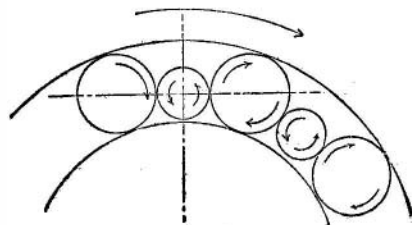


FIG. 5

mechanical engineer has achieved a tremendous practical result when he has succeeded in exchanging a sliding contact for a rolling one.

In this article it is proposed to deal with the elimination of friction from ball bearings. This is a matter of great practical importance for the reason that ball bearings are no longer merely the "playthings" of the mechanical engineer. They are, of course, still used in electric fans, carpet sweepers, and baby carriages, as there is no doubt of their suitability for these pur-

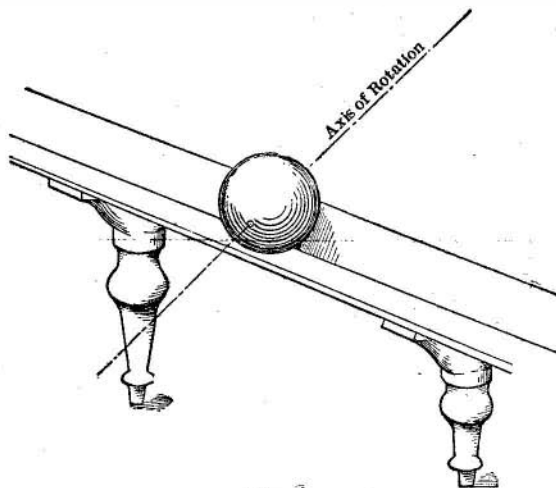


FIG. 6

poses; but they are being increasingly applied to heavy service, and the making of balls has greatly progressed, one at least of our manufacturing companies making and listing steel balls as large as 4 inches in diameter. Ball bearings are being applied to uses where the loads run to twenty-five and fifty tons. They are here to stay, because when constructed in accordance with designs available, with the accuracy possible, and with the steels obtainable, they are capable of tremendously exacting service. The experimental stage is rapidly being passed.

## SOURCES OF FRICTION IN BALL BEARINGS.

There are at least four sources of friction in ball bearings. I enumerate them thus: (1) Rolling friction,

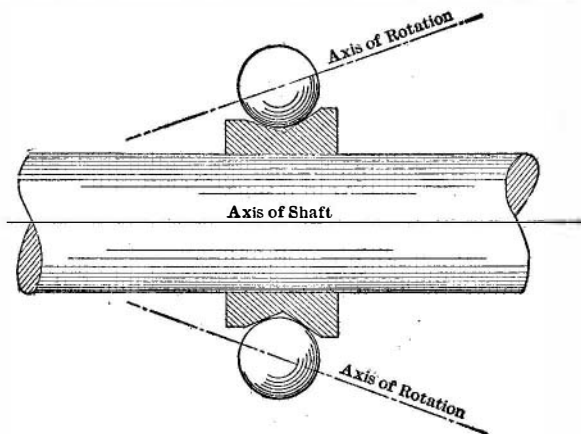


FIG. 7

tion, arising from the fact that the parts in rolling contact are not absolutely smooth surfaces, and also from the circumstance that contact is so limited; (2) sliding friction, arising from the contact of balls with balls; (3) in four-point bearings, the conflict of the axis of rotation set up by the inner raceway with the axis of rotation set up by the outer raceway; (4) friction arising out of the surface-grind set up through compression between the ball and the bearing surface

at a time when this surface is not parallel with the instantaneous axis of rotation of the ball.

The first source of friction—that is, the friction

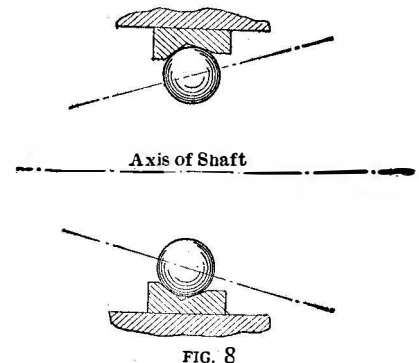


FIG. 8

arising from rolling contact—is largely eliminated by increasing the hardness and smoothness of the balls and raceways. The second source of friction—that which arises from the sliding contact of balls with balls—has attracted the attention of many inventors. The point should be emphasized that this friction is a "sliding" and not a rolling one. A little attention to the subject will convince one that the balls are rotating in opposite directions at the point of their mutual contact. It would seem that the only effective means of eliminating this source of sliding friction is the introduction of a ball or roller, or the equivalent, between consecutive bearing balls in such a manner that the separating means is not in pressure contact with

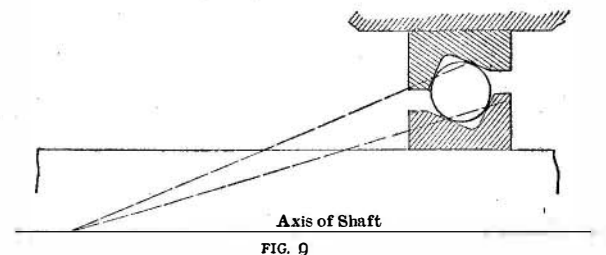


FIG. 9

either raceway. (See Fig. 5.) A separating device which does not roll would have but little effect, apparently, as the slide would still remain. It is not the writer's purpose to treat of the two preceding sources of friction in detail, but to devote the most attention to the third and fourth sources. Taking up the source of friction to which four-point bearings are subject, and which consists in the

## CONFLICT OF THE AXES OF ROTATION,

a little consideration will convince one that when a ball is rolled in a V-shaped groove an axis of rotation is set up. That is to say, two surfaces of contact are sufficient to determine an axis of rotation. An example of this is seen when a ten-pin ball is rolled in the return trough (Fig. 6). Here an axis of rotation is immediately set up. Now this same thing is true whether the ball is rolled along a straight groove, as in the example just cited, or whether the ball is rolled in a circular groove. At every instant it has a certain definite axis upon which at that instant it may be regarded as rotating. Such a definite axis of rotation is set up by a V-shaped groove on a shaft, Fig. 7, and also a definite axis of rotation is set up independently by the V-shaped groove in the housing, Fig. 8. In a four-point bearing these two V-shaped grooves exist simultaneously. And so, in consequence, there result simultaneously the efforts of the two grooves each to

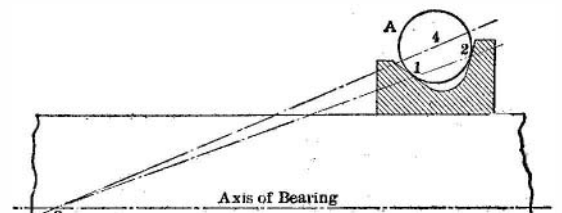


FIG. 10

set up its respective axis of ball rotation. It becomes, then, a matter of considerable importance that these two axes of rotation shall in reality not be two, but one single axis. That is to say, it is important that the axes should coincide (Fig. 9). Otherwise, there is a contest between the two separate axes, which will give rise to a sliding friction.

## HOW TO FIND THE AXIS OF ROTATION.

It will be instructive to point out how the axis of

\* Power (N. Y.)

rotation set up by the contacting surfaces of a V-shaped groove may be found practically. By referring to Figs. 10 and 11, it will be seen that the ball 4 contacts with the bearing ring at the points 1 and 2, Fig. 10, and at the points 5 and 6, Fig. 11. Draw a straight line through 1 and 2, or through 5 and 6, and prolong it until it intersects the axis of the bearing at 3. Draw a straight line through 3 and the center of the ball 4. This line 3—4 is the axis of rotation. It will readily be seen that in order to avoid conflict of the axes when both inner and outer V-shaped grooves occur in one bearing it becomes necessary that the

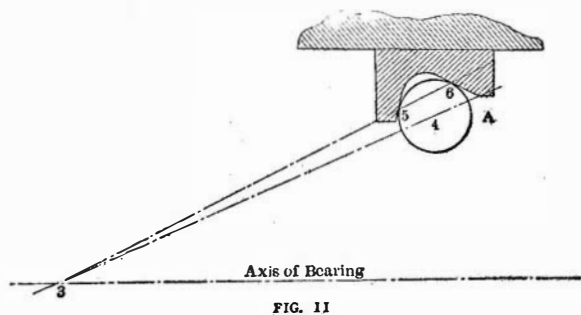


FIG. 11

lines 1—2 and 5—6, when prolonged, shall meet the axis of the bearing at the one point 3, Fig. 12.

Some years ago this matter was dealt with in effect by an Italian inventor named Casalegno. He seemed to think that when he got the lines 1—2 and 5—6 to intersect the axis of the shaft at the same point he had eliminated all sliding friction—at least, all sliding friction due to contact of balls with rings. He was in error as to this, as will appear in the sequel.

Before passing on to the next source of friction it will be instructive to call attention to an unnecessary restriction to which this same inventor thought it necessary to subject the three-point construction. He thought that when one of the bearing rings presented a single surface to the ball instead of a V-shaped groove, the prolongation of this single surface should pass through the point 3, Fig. 13. In this he was mistaken, in so far as the harmonization of velocities is concerned, for the following reason: One point of contact between a surface and a rolling ball is not of

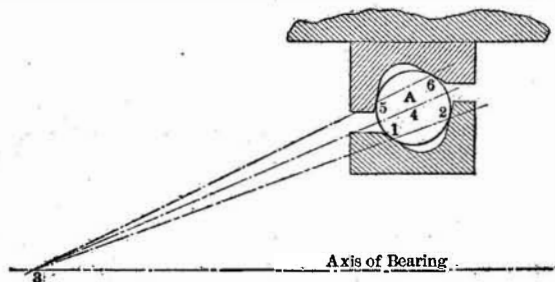


FIG. 12

itself sufficient to determine a definite axis of rotation. In fact, it harmonizes with any axis whatsoever. If one of the bearing rings, say the inner, has two points of contact with the ball, Fig. 14, and consequently determines a definite axis of rotation, the one point of contact between the outer ring and the ball will not set up an additional axis, but will accommodate itself to the one set up by the inner ring. And it does not matter where this point of contact of the outer ring is situated. The restriction that it should be so located that the tangent at this point would pass through 3 is unnecessary. In three-point bearings, then, the conflict of axes which we have been considering does not occur.

#### THE MOST SERIOUS SOURCE OF FRICTION.

Regarding the fourth source of friction—that which arises from the actual rotation of a ball relatively to the contacting surface—if steel balls and steel bearings could be made absolutely smooth and incompressible, and not subject to minute flakings arising from inadequacy of support, this trouble would not arise. As it is, however, the trouble exists and constitutes perhaps the most serious source of friction to which

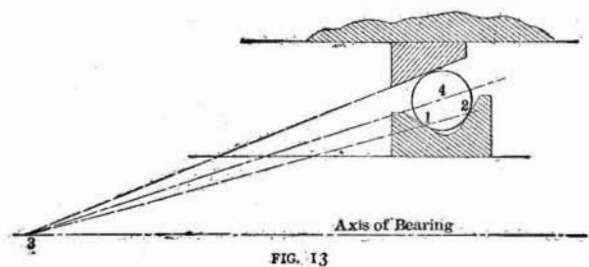


FIG. 13

ball bearings are liable. By referring to Fig. 15, which shows to a greatly exaggerated degree the compression between the ball and the race, it will be noticed that the line 1—2 is not parallel to the surface of contact, but makes an angle with it.

In order to comprehend clearly the source of friction which the writer is about to explain it will be necessary to understand somewhat the character of the line 1—2. The technical name for this line is the *instantaneous axis of rotation*. Its character is this:

If we take our position on the bearing ring and, disregarding its motion, pay attention only to the motion of the ball relatively to this bearing ring, we shall observe that all points on this line 1—2 are quiescent, that the ball is in fact rotating about this line as an axis. This is the reason for calling the line an axis of rotation. But this axis of rotation is good for an instant only. As the ball rolls, there is a constant change of axis. It is therefore appropriate to call it the *instantaneous axis of rotation*, seeing that it is the axis for the instant only.

This rotation of the ball relatively to the contacting

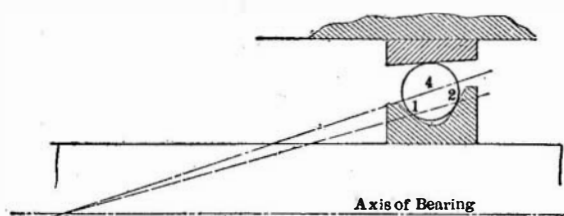


FIG. 14

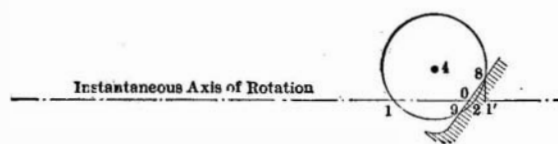


FIG. 15

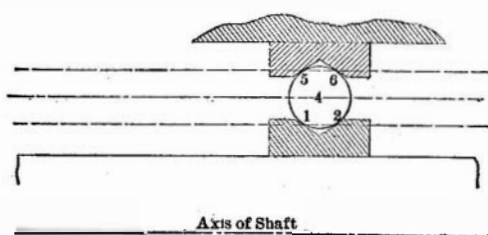


FIG. 16

surface is complicated with compression. By referring again to Fig. 15 it will be seen that all points of the line of contact 8—9, except 0, which is quiescent, are swinging in circles about the line 1—2. Thus, 8 swings in a circle whose center is 1' and whose radius is 1'—8. That this gives rise to sliding friction is quite clear. That this friction is approximately proportional to the pressure along 1—2 would seem to follow as a consequence. It will be readily granted by those who have followed this discussion that here is a most serious source of sliding friction. It will be observed, however, that it disappears as the angle between 1—2 and 8—9 is diminished. It becomes very important then, from the point of view of the elimination of this source of friction, that this angle should be made as small as possible. The result of all this is that flat raceways are an absolute requirement. By

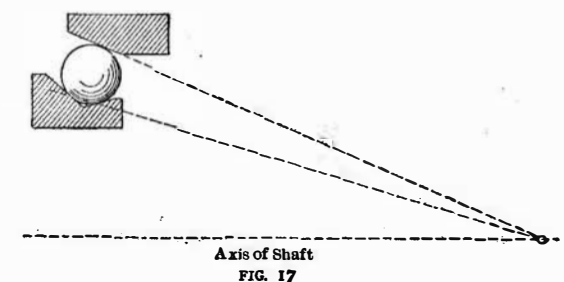
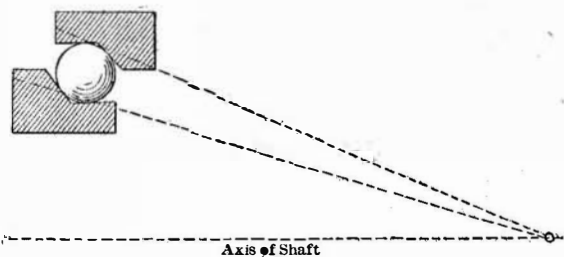


FIG. 17

*flat raceways* is meant raceways whose sides are parallel, or approximately so, to the corresponding instantaneous axis of rotation. Examples of such raceways are shown in Fig. 17. In contrast with these are shown in Fig. 18 examples of incorrect forms.

In applying these principles to the special cases where one instantaneous axis of rotation is parallel to the axis of the shaft, let it be noticed that this will have the effect of carrying the point 3, where the instantaneous axis and the axis of the shaft meet, off

to infinity. This will result in requiring the other instantaneous axis to be parallel to the axis of the shaft. So also with the axis of rotation itself. This is brought out in Fig. 16. In such cases it is necessary that all bearing surfaces should be parallel, or approximately so, with the axis of the shaft, at least at the several points of contact.

Probably the great bulk of ball bearings, if we except a few styles made in the last few years, have been constructed on more or less erroneous fundamental principles. The time is at hand when a tremendous increase in the application of ball bearings to heavy machinery is about to take place. It is therefore important that the fundamental conditions should be discovered and made known. It is hoped by the writer that the present article is a serious contribution to this difficult subject.

#### THE ACTION OF STEAM IN CYLINDERS.

THOUGH Hirn, by his careful experiments and scientific investigation, may be admitted to have laid pretty firmly the foundation of the theory of steam action in a cylinder and to have thoroughly established the theory of cylinder condensation, certain experimenters in Great Britain have for some time been seeking doubtful laurels in overturning Hirn's conclusions, or rather should we say in endeavoring to overturn them, for it cannot be said that any convincing figures have been advanced by the new school. Indeed, from figures which have appeared from time to time it may be said that the conclusions drawn by Hirn are

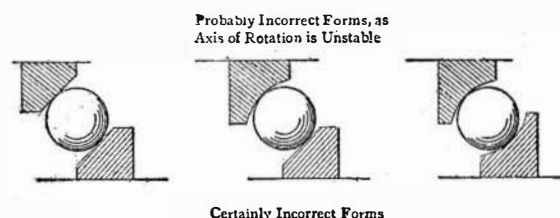
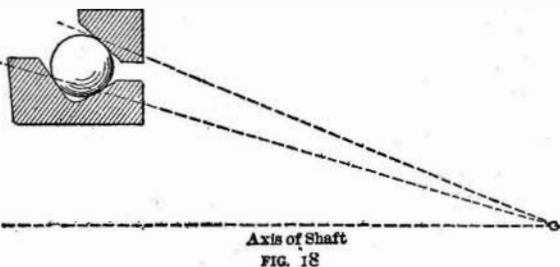
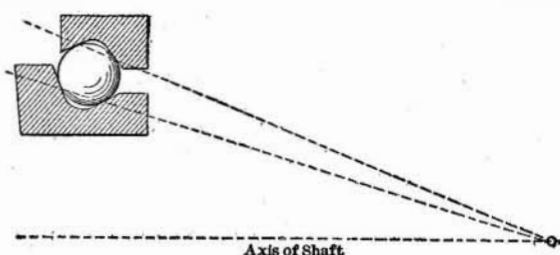


FIG. 18



strengthened rather than that the contentions of the new school are in the least borne out. Hirn, it is well known, argued that since the steam in a cylinder is constantly varying in pressure and therefore in temperature, the cylinder metal must be continually striving to attain the same temperature as the steam. The steam and the cylinder metal are but a very brief time in contact, and it is argued by the new school that this time is too short to produce the effects noticed, so the theory of leakage is advanced to explain the facts. A study of the indicator diagrams certainly gives no support to this hypothesis. The Engineer, of London, now comes forward and endeavors to show that even if the time of exposure of the steam to the cylinder surfaces is not sufficient to allow of the interchange of heat sufficient to produce the results so well known, it is possible that a film of water globules on the surface would do so. We admit that this is so and we see no objection whatever to this rendering of Hirn's theory. Indeed, we never knew an upholder of Hirn to omit the consideration of water action. Is not the cry for superheat simply an endeavor to abolish the film of water? Has it not always been held that if there be no water to re-evaporate there can be little cylinder cooling and so again still less water?

But granting that the metal surface reactions are intensified by water globules, we would have no one forget in this contention that when the gases from a boiler furnace pass over the heating surfaces of a boiler they do so at a high velocity, yet they lose their heat in an incredibly short space of time. Thus in the