Bearing Metal Manufacturing and Use*

The Characteristics of Metals Used for Bearings

By L. D. Allen

"It is not work that kills men, it is worry." It is not motion that destroys machinery, it is friction.

Friction, a destructive agent, constantly piling up waste and expense, is everywhere. And yet, of the many details connected with the operation and care of machinery, it is doubtful if any receive less attention than the reduction of friction. In many installations, the shafting alone requires from 20 to 30 per cent of the power developed by the engine, and in some cases these figures are probably greatly exceeded. Comparatively few realize the significance of these figures, which mean that of every ton of fuel consumed some 400 pounds or more are wasted in overcoming friction. Much of such waste can be greatly reduced, but in the rush of getting out work, such as prevails in many mills and factories, few, if any, have the time and patience to go into details and correct bad conditions. The prevailing idea seems to be that greatest economy will be effected by buying at a low price rather than by securing efficiency and reduction in wear through the use of suitable material and methods.

Power lost through friction is converted into heat, which under normal conditions is radiated as fast as produced, the bearing surfaces remaining at or near the temperature of the surrounding air. If the heat is generated faster than it is dissipated, a hot or fused bearing will result. For this reason, the anti-frictional properties of a bearing metal are more desirable than tensile and compression strength. Many judge a metal by its compression strength and its tin content, whereas, under high speed, metals high in tin are usually the first to heat and fuse. It makes no difference how much tin a metal contains, how hard it is or how great its compression strength, if it heats it will soon fuse and run out of the bearing, and under such conditions it is no better than so much lead.

CAUSE AND COST OF FRICTION.

Resistance to motion—friction—is great or small according to the roughness or unevenness of the surfaces in moving contact. In reality, there are no absolutely smooth metal surfaces. A surface may seem smooth to the touch, but by means of a powerful lens, minute projections, roughness and unevenness may be seen, which create the resistance. By proper lubrication, a film of lubricant is established and maintained between the rubbing surfaces which tends to prevent the irregularities from meshing. The conditions for this film are favorable only to such extent as the bearing and shaft are smooth.

To a greater extent than most people realize, the "cost of the babbitt or the lubricant is the cost of the friction accompanying the same."

A concern may spend several dollars less, per hundred pounds, for a babbitt that will show apparently satisfactory wear, but the question is how much money does this concern spend on other things as a result of the friction developed from the use of this particular babbitt. It may not even heat in a slow-running bearing, but if it is low in anti-frictional qualities, it communicates to the other parts of the machinery a certain amount of pull and drag, and this percentage, even though small in any one bearing, develops to considerable proportions in the aggregate friction of all the bearings throughout a plant.

BABBITT REQUIREMENTS.

The requirements of a babbitt are: First, that it be composed of metals least susceptible to frictional contact; second, that it possess the sustaining properties necessary to carry the load imposed; third, that the ingredients be so treated, reduced and combined as to produce an even, smooth, unctuous surface, which will minimize interlocking, abrasion and friction in its various forms.

The metals used in the manufacture of the various babbitts, type metals, solders, etc., are two or more of the following: Tin, lead, copper, antimony and bismuth. Some idea of the bearing value of these different metals may be derived from the properties of each as enumerated herewith.

PROPERTIES OF TIN.

Tin is a white metal with a yellowish tinge. It toughens the alloy, lowers the melting point and assists in producing a strong, homogeneous mixture. It is a "dry" metal, that is, somewhat lacking in anti-frictional properties. Under heavy friction, it heats quickly and fuses. Over direct heat, it melts at about 450 deg. Fahr.; its specific gravity is 7.35. The grade generally used in the manufacture of babbitt metals is known as Straits tin. There are now in this country a number of detinning concerns which are producing a nearly pure tin by either

a chemical or sweating process from old scrap, tin cans, etc. This is now being used extensively in the manufacture of babbitts and cheap solders, as it can be bought at about a cent per pound under the market price.

LEAD.

Lead is another ore product and imparts softness, lowers the melting point and reduces the tendency to heat. It reduces friction more than any other metal, resembling graphite in this respect. It melts over direct heat at about 620 deg. Fahr., and its specific gravity is 11.38. In many sections, considerable antimony ore is found combined with the lead ore, so that in the process of refining the lead, a slag or by-product results, which is known as antimonial lead. This is put through a further refining process, which does not separate the lead from the antimony, but removes considerable of the impurities such as iron, arsenic, etc. The resultant product usually contains anywhere from 12 to 22 per cent antimony, the rest being lead and some impurities. This antimonial lead is used in making cheap babbitts, type metals, casting metals, etc., for competition where a low price is necessary.

COPPER.

Copper hardens and toughens the alloy and raises the melting point. It slightly increases friction. It melts at a temperature of 1,943 deg. Fahr., and its specific gravity is 8.85. Copper is the basis metal in bronze, brasses, etc. Very little of it is used in babbitt metal, from 0.25 to 0.5 per cent in a lead-based babbitt, although there are some mixtures that contain as much as 10 per cent copper, the hard babbitt, for instance, known as "Hard Genuine," containing 80 pounds of tin, 10 pounds of antimony and 10 pounds of copper. Copper and lead are not particularly fond of each other. The writer does not care for copper in a lead-based babbitt; it hardens the babbitt somewhat, but it reduces the anti-frictional value.

ANTIMONY.

Antimony is an imported ore product. It is a hard, brittle, bluish-white metal of crystalline structure. It hardens an alloy and raises the melting point. It is a great reducer of heat, and it also reduces friction. It melts over direct heat at about 1,169 deg. Fahr., and its specific gravity is 6.76. The crystalline grain or fracture in a babbitt is due to its antimony content. Some very carefully and scientifically conducted tests indicate that the best babbitts should not contain over 13 per cent antimony, as the evenness of the alloy and its wearing qualities are greatest at that point.

BISMUTH.

Bismuth reduces friction and prevents shrinkage. It lowers the melting point and expands on cooling. It melts at a temperature of about 507 deg. Fahr., and its specific gravity is 9.82. As bismuth usually costs more than \$2 per pound, it is not at all popular with the babbitt manufacturer.

ALUMINIUM.

Aluminium is rarely used in a babbitt. It imparts some toughness by closing the grain and acts as a flux. It slightly increases the friction which offsets its toughening properties and makes it of no practical value in a babbitt.

Certain combinations of tin, copper and antimony shrink on cooling. Tin and lead alone shrink slightly, and antimony remains about constant. Any two metals mixed together in the form of an alloy produce a metal which melts at a lower temperature than the original metal having the higher melting point, and in some cases, lower than the metal with the lower melting point.

CLASSIFICATION OF BEARING METALS.

Bearing metals or linings may be classified under two heads, babbitt metals, which are largely tin, lead, antimony and sometimes copper compositions, and brasses and bronzes, which are tin, copper and zinc compositions, sometimes containing certain percentages of lead.

Babbitts range in composition from a cheap metal containing 90 pounds lead and 10 pounds antimony, to mixtures containing about 88 pounds tin, 4 pounds copper and 8 pounds antimony.

Babbitt metals are divided into three classes, the lead-based anti-friction metals, which are metals in which the lead content is the heaviest, the smaller percentages being tin and antimony; the semi-tin-based metals in which the tin and lead contents are about equal, leaving room for from 10 to 20 per cent antimony; and the tin-based metals, which range from 75 pounds up to 90 pounds of tin in each 100 pounds.

I have knowledge of over 200 different babbitt mixtures that are in actual use, whereas only about 7 or 8 are really necessary. Babbitt metals should be made according to certain exact percentages, or so constructed

as to be evenly balanced, so as to produce perfectly homogeneous mixtures or alloys, in order that a combination may possess its maximum strength and hardness.

BEARING-METAL MANUFACTURERS.

There are four kinds of bearing- and type-metal manufacturers.

The first is the smelterer who buys and refines drosses, scrap metals, etc., and converts the resultant product into different grades of babbitt metals, type metals, solders, etc. He sells to a large trade, which is influenced or attracted by a low price; its requirements are large in the matter of quantity, but not exacting in the matter of quality.

The second is the man who installs a kettle, buys tin, lead and antimony and mixes them in certain proportions according to some one or set of published formulas. Not only are these published or analytical formulas, as a rule, incorrect, but they have very little to do with the details of producing the right kind of finished product. The amount of business he does is in proportion to his luck and hustle.

The third is a combination of the two foregoing classes.

The fourth is the experienced alloyist who has studied the properties of all the different metals, so that he knows which will combine best and how best to combine them—the best temperatures and fluxes to employ, etc. He has also, to combine with the foregoing data, a practical knowledge of the uses to which the metals are put. This type of man gets the discriminating, careful trade, which makes a thorough study and test of its needs and demands results accordingly, or which, in buying, places quality first.

MANUFACTURING REQUIREMENTS.

Many years of practical experience with the formulas and manufacturing methods employed by different babbitt manufacturers both in the United States and abroad, coupled with deductions from results shown by expert analytical and mechanical tests and under actual working conditions in nearly all kinds of machinery, indicate conclusively the following facts:

The best amalgams are produced by the alloying method. This requires the use of several furnaces, pure materials, and consists in making up, at suitable temperatures, certain primary combinations of affinity metals; then taking such quantity of each combination as is necessary to produce the required grade and alloying the same under suitable temperature into the finished product. Metals may be well mixed, but the quality and permanency of the mixture are determined by just such solubility laws as control ordinary solutions. Certain perfect amalgams at high temperature become partly separated amalgams at low temperature; others there are that remain perfect amalgams at any temperature.

In the use of the lead-antimony and the lead-antimony-tin mixtures a complete reduction of the crystal formation is important to insure smooth, mirror-like, non-abrasive bearing surfaces. All the ingredients must be evenly balanced and distributed throughout the alloy. It is for this reason that a lengthy annealing period is desirable because it has been found to have a greater effect on the mechanical properties of a metal than the temperature factor.

The tin, copper, zinc, aluminium, nickel, etc., amalgams are the most difficult to produce. They require skill and care in the introduction of deoxidizing agents, such as magnesium, phosphorus, silicon, etc.

VIRGIN VS. OLD METAL.

Very often large babbitt users who have their own formulas specify that "virgin" metal be used. Metallurgists claim that it is not a question of whether virgin metal or old metal be used so long as the metal is "pure," free from dissolved or mechanically entangled oxides. It is the oxides and impurities that impair repeatedly overheated or remelted metals. Some good authorities claim that the dross of tin, lead and antimony products (when free from iron, aluminium, zinc and arsenic) and smelted in an adequate reducing furnace at above 2,500 deg. Fahr., will, with the proper additions made to the resultant metal, produce amalgams that are superior to the same amalgams made from all virgin metals, because the amalgams will be better alloyed than when virgin metal is used. My experience, however, leads me to doubt this and to believe that chemically pure, perfectly balanced amalgams made of virgin metal produce the surest and strongest babbitt metals made, and that they possess higher anti-frictional properties.

CHEMICAL ANALYSIS ALONE NO GUIDE.

A babbitt should not be selected on analysis, as there is much that enters into the making of the metal, and

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that has to do with its physical properties, that evades the chemists. Nor should one babbitt be selected for all bearing requirements. Metals heavy in lead are best anti-frictionally when properly alloyed, but metals heavy in tin and copper are also desirable where toughness combined with hardness is required to meet unusually severe or irregular bearing conditions.

Considering the price of lead and antimony, there is no legitimate reason for paying 18 cents to 25 cents per pound for bluish-looking or leady-looking metal, the tin content of which is usually not over 15 per cent, and often below 10 per cent. On the other hand, considering the high price of tin, no one should expect to pay much, if

any, below the market price of tin for the whitish-looking or tin-based metals, or to go much below a medium figure for the semi-tin-based metals which are also white in appearance.

Babbitt troubles are often due to a good many things other than the babbitt itself. Some of these things are a selection of the wrong grade of metal; the wrong application of the metal; irregular bearing conditions; bad lubrication; neglect, etc.

The safest course for the purchaser who wishes to secure the best bearing values is to place his babbitt orders with such manufacturers only as are thoroughly experienced in bearing requirements, who know just

what metals or combinations of metals possess the best endurance and anti-frictional properties, who are also thoroughly skilled in alloying and combining metals, and, as well, honest and conscientious in their trade relations.

Prices and analyses are usually dangerous factors to rely upon in the selection of a babbitt. The size of the bearing, the thickness of the lining, and the speed and load conditions should influence the choice. A properly made, hardened and strengthened lead-based babbitt will, oft-times, due to its naturally better anti-frictional properties, give better service than an expensive tin-based metal.

The Radiation Problem*

By E. E. Fournier d'Albe, D.Sc.

THE radiation discussion, which was one of the most notable features of the Birmingham meeting of the British Association, appears to have created a general impression that some radical revision of our ideas as to the nature of radiation must now be regarded as unavoidable. It may therefore be of interest to give a brief summary of the present state of the problem.

Its acute phase has been brought about by the remarkable successes achieved by some forms of what is known as the "theory of quanta." This theory, or rather hypothesis, assumes that not only matter, but energy itself, has an atomistic or discontinuous structure, particularly when it is flung out into space in the form of radiant energy or radiation.

Are we, then, drifting back to a corpuscular emission theory of light, destined to replace the now generally accepted wave theory? Such a return to older views would not be altogether without precedent. History has witnessed similar fluctuations of view as regards the shape and motion of the earth, and as regards the structure of electricity. And the triumphs of atomistic conceptions in other fields, achieved with the aid of radioactivity and of Brownian motions, make the propaganda for a further extension of the atomistic principle easy. R. A. Millikan¹ maintains that the number of atoms and molecules in a given mass of matter may now be counted with as much certainty and precision as we can attain in counting the inhabitants of a city. With the characteristics of these inhabitants we can deal by means of the science of statistics, and the adherents of the new atomistic theory of radiation would have us apply statistical methods to an immense range of physical investigations.

But the hypothesis of "quanta" or irreducible and indivisible elements of energy is not merely atomism gone mad. There are certain undeniable and undoubted facts which find their simplest explanation in the hypothesis of a discrete structure of radiant energy.

Chief of these is the observed mode of transfer of energy from cathode-rays to X-rays, and *vice versa*. Cathode rays are electrons projected with enormous velocities. The stoppage of an electron by the target in the Roentgen tube generates an X-ray pulse. All electrons are stopped within a time which is the shorter the greater their energy of motion. Hence the X-ray pulse generated is "thin" in proportion as its energy is great. The more rapid the cathode rays, the thinner, "harder," and more penetrating are the X-rays.

Now the beautiful recent work on the reflection and interference of X-rays, often referred to in *Nature*, has proved that these rays are covered by the wave-theory of light. The X-ray waves are some 10,000 times shorter than the shortest ultra-violet light waves known. They have, like ordinary light, a wave-length, or rather a range of wave-lengths, and the energy of every X-ray wave is proportional to its frequency, since the thinner and "harder" pulses have the smaller wave-lengths.

But this is not all. When X-rays impinge on a target, electrons are projected from it; they in turn constitute cathode rays. The velocity of these electrons is independent of the intensity of the X-ray beam. It only depends upon its "hardness," i. e., its frequency, or the reciprocal of its wave-length. To put it in the language of visible light, the velocity with which an electron is expelled from the target depends, not upon the "brightness" of the X-rays, but solely upon their "color," and is the greater the more that color tends toward the "blue" end of the spectrum.

Moreover, those electrons which are not expelled from the material exposed to the X-rays appear to be quite unaffected, and they form the vast majority of the electrons present, unless a particular "characteristic frequency" is used for the existing rays, whereupon the electrons come out in enormous numbers.

The handing on of a quantity of energy intact from X-ray to cathode-ray and back to X-ray was used to support an atomistic view of the X-rays themselves, until it was found that the same rules apply to the

liberation of electrons by ultra-violet light. Here arose a dilemma: either ultra-violet light itself (and probably all radiation) is atomic, or there is some mechanism by which radiant energy can be absorbed until a definite quantity (proportional to the frequency) is accumulated, whereupon an electron is expelled. The remarkable thing is that this energy of the electron is actually derived from the light, so that the latter does not simply liberate internal energy by some sort of "trigger" action.

All this might not have ensured a hearing for an atomistic hypothesis of energy had not Prof. Max Planck (now rector of Berlin University) put forward a theory of radiation based upon quite other considerations, which also involved an atomic structure of energy, at least when radiated.² He was endeavoring to explain the experimental fact that the total heat of all wave-lengths radiated by a black body (not a blackened body, but the "ideal" black represented, say, by the mouth of a deep cave) is proportional to the fourth power of its absolute temperature, and found that no formula completely representing the relation between the frequency and the amount of energy associated with it could be written down unless the energy was flung out by each molecular radiator in definite amounts or "quanta" proportional to the frequency, i. e., inversely proportional to the "wave-length." This immediately accounted for the fact that, as a body gets hotter, it passes from "red" heat to "white" heat (i. e., toward higher frequencies) until, when we reach the temperature of the sun, the maximum energy is well within the visible spectrum.

The actual magnitude of the supposed quanta is excessively small. For a frequency of one vibration per second, it would only amount to 6×10^{-27} erg, a quantity known as the "action constant." For frequencies like that of green light (600 billion per second) it would still only amount to some billionths of an erg, but such is the marvelous sensitiveness of the eye, that it can detect light (say, from a star of the sixth magnitude) when the amount of energy passing through the pupil is only some 300 or 400 quanta per second.

What, then, is the mechanism of this radiation by quanta? Are we to suppose that it resembles the sound waves proceeding from the incessant but irregular rifle fire of a large army, in which each soldier gradually accumulates sufficient powder to fire his shot? Or is it atomistic, like the bullets? Or must we fall back upon Sir J. J. Thomson's bold but rather appalling conception of a gigantic web of countless threads pervading the universe, in which each thread connects a positive and a negative electric atom, and bears its trembling message along with the speed of light in a single direction?

Whichever view may be finally adopted, we may be sure that the investigation of this fascinating problem will teach us a great deal about the interstellar ether which conveys the messages. The recent German attempt to explain away the ether, known as the electromagnetic "Principle of Relativity," has failed in its main object. *Gehreke*, in his preface to *Drude's "Lehrbuch der Optik,"* describes that principle and its temporary sway as "the most notable case of mob suggestion since the days of the N-rays." The hypothesis of quanta is saved from a similar failure by keeping in close touch with experiment. In the hands of *Nernst* and *Lindemann* and *Debye*, it has been used with brilliant success for investigating and explaining the fall in the specific heat of all bodies as we approach the absolute zero of temperature. The specific heat probably begins by being proportional to the cube of the absolute temperature, so that the heat energy of the body is proportional to the fourth power, thus recalling the *Stefan-Boltzmann* law of total radiation already mentioned.

Planck's "action constant" has turned out a most useful quantity in all sorts of investigations, and, although its actual nature is somewhat doubtful,³ it may yet turn out to be, like the velocity of light, one of the fundamental constants of nature.

But before any quantum theory of radiant energy can be accepted, it must make its peace with those phenomena (chiefly diffraction and interference) which overthrew Newton's emission theory, and established the

*"Vorlesungen über Wärmestrahlung," 2nd edition. (Leipzig, Barth.)

³It is an energy divided by a frequency, but also has been regarded as an angular momentum.

wave theory of light. That has not yet been done, or even attempted, so there is but little prospect as yet of a decisive battle.

Correspondence

[The editors are not responsible for statements made in the correspondence column. Anonymous communications cannot be considered, but the names of correspondents will be withheld when so desired.]

Mnemonic Rule for the Constant π

To the Editor of the SCIENTIFIC AMERICAN SUPPLEMENT:

I was much interested in the French mnemonic for π which appeared in your issue of the 17th January. On consideration, however, it appeared to me that the device presented two defects—it was rather a lot to write out the words and then count the letters, and there seemed a probability that some words might be transposed, and even that two lines might be subject to the same error. I therefore set myself to devise a more mechanical mnemonic, and I venture now to submit the result.

There being no O in the series I take the first nine consonants to represent the units digits. These naturally falling into three groups separated by vowels considerably facilitates memorizing. Thus:

1	2	3	4	5	6	7	8	9
B	C	D	F	G	H	J	K	L

As the mnemonic may be useful for other sets of figures I should allocate letter M as the cipher.

These letters from B to L alone then have numerical significance—all consonants after M and all vowels may be ignored.

I now allocate these letters to the value of π , which I also divide into ten groups, getting nine groups of three and one of four figures. Thus:

3.14	159	265	358	979
DBF	BGL	CHG	DGK	LJL
323	846	264	338	3279
DCD	KFH	CHF	DDK	DCJL

Now all that is required is to select words for these ten groups of letters; and, so that transposition of the various groups shall not be possible, their order is determined by making the initial letter of a word to serve as an index of the position of the word; that is, the first group begins with B, the second group with C and so on, each "word" having four significant letters in proper order, first the index letter and then the letters of its group. For example, 3.14 may be represented by "braiseD BeeF"—the initial tells that the "word" is the first of the set; D (= 3) is the next significant letter and B (= 1) and F (= 4) are the only other significant letters. Obviously, other words might be selected giving the same result, "bad" and "brief" being examples.

On these lines I have selected the following series:

braiseD BeeF	=	3.14
caB GLass	=	159
disCHarGe	=	265
fonD GreeK	=	358
giLt JeweL	=	979
harD CoreD	=	323
junK FisH	=	846
kerCHieF	=	264
lanD DraKe	=	338
maD CaJoLer	=	3279

It will be seen that groups of three figures can be rigidly located, so that dislocation is scarcely possible; and as regards the various groups, it is well recognized that knowledge of the first letter of a wanted word is one of the most valuable of mnemonics. Doubtless a little more research would lead to a better selection of words, but even such a bizarre word as "junkfish" with its few non-significant letters has some advantages as a mnemonic.

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*Reproduced from *Nature*.

¹*Science*, vol. xxxvii, p. 119, January 24th, 1913.