steels. Modern case-hardened carbon steel which gives a schleroscope reading of 95 can just be scratched with a very fine Swiss file.

This class of gearing, because of the price at which it could be marketed, was manifestly a great improvement in economy of operation, wherever it might be found sufficiently strong to withstand the shocks of service. No test, other than that of service, has been devised for determining its resistance to service stresses, but that the limit of its strength is below the requirements of the heaviest modern service appeared probable and has since been demonstrated. In the first days of its use much virtue was attributed to the toughness of the low carbon core, but this toughness cannot manifest itself under stresses on the whole tooth, and a tooth strained beyond its strength breaks short. It is evident that substantially the entire tooth strength must be found in the hardened case, and the factor of safety, even with the enormous elastic limit of this high carbon case, promised to be too low for safety in the heaviest equipments throughout the very long period of its probable service. Although this gearing has been used very conservatively on motors of

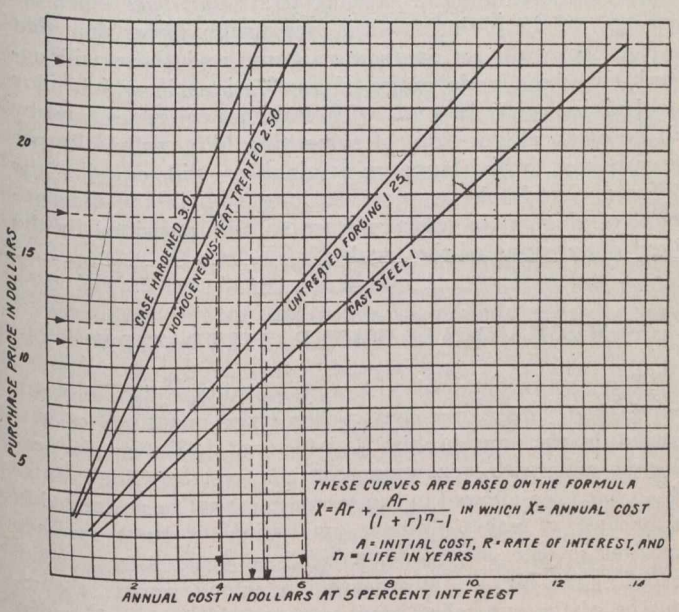

Fig. 2.

over 125 h.p., and then only in the light of careful study of operating conditions, the original estimates of strength have been closely borne out. Breakage has occurred in certain carefully watched test equipments after two years of service where wear had hardly begun. This has in some cases undoubtedly been due to fatigue of the case from repeated shocks closely approaching the elastic limit, and in other cases to subsidence of the soft tooth core resulting in cracking of the case.

It is therefore known to-day that, while with motors of less than about 100 h.p. this type of gearing is sufficiently strong to resist fatigue until worn out in service, its application with heavier equipments can only be advised in the light of a very definite understanding of the conditions of operation. With such heavier equipments, especially in high speed service with rapid acceleration and liability to abnormal shocks such as are produced by commutator flash-overs or line breaks at the collector, the case-hardened gearing appeared and has already been proved to have an inadequate factor of safety.

Attention was then turned to a modification of the homogeneous heat-treated gearing with a view to increasing its hardness to attain increased life and a greater elastic limit, which was essential in order to defer fatigue beyond the extended limit of wear. The physical characteristics of heat-treated steels depend upon a considerable number of variable factors in the constitution of the steel, the manner in which it is worked, and methods of treatment. The constitution of the material can only be definitely controlled within certain limits which are well recognized in steel manufacture, and variations in the constitution affect final physical characteristics, though the variations may be corrected in a measure by corresponding variations in treatment. Such methods, if carried to too great a refinement, are prohibitively expensive, and the development of the desired new type of gearing involved a method of analysis and an adjustment of treatment which would be commercially practicable.

The type of heat-treated gearing which had become recognized as a heavy service standard showed elastic limit varying in regular production from eighty to ninety thousand pounds per square inch, although occasionally specimens showed still higher values and certain other specimens with elastic limit varying down to 70,000 lb. per square inch were put into service in the earlier days of this development. Throughout several years a record was kept of mileage and physical characteristics of all specimens broken in a service of known character, and the curve in Fig. 1 shows relation between elastic limit of broken specimens and the time required for fatigue to the breaking point in normal service.

This shows that maximum stresses on the gear teeth, which could be determined in no other way, are equivalent to about 70,000 lb. per square inch in the teeth, since all specimens broken early in service show approximately this value. Higher values are shown to afford longer life, until the specimens broken toward the limit of wear invariably show an elastic limit of approximately 80,000 lb. per square inch, and in no cases have specimens showing higher values broken in service.

With a lower ductility, it was assumed—and it is in all probability true—that a larger factor of safety would be necessary to defer fatigue beyond the limit of wear, and a composition was selected and methods of working and treatment determined which would give an elastic limit of 140,000 to 150,000 lb. This steel shows a hardness approximately 500 in the Brinnell scale, and, while no very definite comparison with hardness of case-hardened gearing is possible, such rough comparison of the Brinnell and schleroscope scales as is possible and the file test indicate the hardness to be approximately 85 per cent. of that of case-hardened gearing.

Commercial application of this type of gearing has been made with the greatest care, and it has not yet been trusted in the heaviest service, although since its first commercial use two years ago about 7,000 equipments of this gearing have been installed with motors of all power up to 150 h.p. and there is no record of breakage of a single tooth within the limit of wear.

It has been pointed out that various factors had contributed to a marked tendency to substitute solid for split gears. This tendency was manifest in all classes of service, and its wide spread made possible the realization of an old idea of using forged blanks in place of castings for axle gears.

The manifest advantage of forgings in entirely eliminating shrink strains and other faults not altogether avoidable in castings was important, but not all of the desired end. It was practicable to machine steel of a higher carbon content, and the strength and toughness could be greatly enhanced by the operation of forging the