FACTORS DETERMINING THE EFFICIENCY OF TROLLEY WIRE.

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No department of electric railroading has received less attention than the transmission line and particularly the trolley wire. In the construction and maintenance of an electric railroad, no expense is spared to obtain power station equipment of the highest efficiency while the trolley wire, which is just as essential for operation is generally purchased with no restrictions on the quality of material.

The entire development of electric traction has taken place within the past twenty-five years, and this short period of time has witnessed an almost fabulous advance in the improvement of power station and rolling stock. Higher voltages, greatly increased electrical output, heavier and more efficient cars capable of increased speeds have been noticeable on all lines. The increasing demands of traffic and the necessity of economical operation have forced the development of machinery of high efficiency. In spite of the great advance along all other lines, the trolley wire of to-day is not essentially different from that at first installed.

At the present time there are over 25,000 miles of electric lines in the United States; calculating the value of the trolley wire in use, at the current price and assuming the average weight per mile as 2,000 lbs., shows a total investment of $8,000,000. This wire is the main artery of the entire system and any injury to it cripples the operation of the road and decreases thereby the efficiency of the expensive generating equipment, and yet an examination of the records of roads operating many hundred miles of track show that a broken trolley wire is almost a daily occurrence.

Numerous attempts have been made to specify the necessary characteristics of trolley wire, some of which have failed because of an incomplete understanding of the demands upon the material and many more on account of ignorance of the processes of manufacture, and the defects inherent to these processes. The determination of the qualities necessary to an efficient material must always be preceded by a thorough understanding of the conditions which it must meet and by a careful study of the material itself and the limitations imposed by manufacturing processes.

The trolley wire in general use in the United States is made from hard drawn copper, the sizes and shape varying considerably, but circular wire having a diameter of 0.364 inches, which corresponds to No. 2-0 on the Brown & Sharpe Gauge is perhaps the most common form of construction. Ordinary soft copper does not have sufficient strength for this service so that reliance has had to be placed upon either steel, bronze or hard drawn copper; while steel wire has the requisite strength it is subject to severe corrosion from the weather and has vastly greater electrical resistance. The silicon, phosphorus and other bronzes of a similar nature possess great strength but all have the serious effect of much lessened conductivity. Soft copper wire has a strength of about 34,000 lbs. per sq. inch, while hard drawn wire can be made having a strength of as high as 67,000 lbs. per sq. inch. Hard drawn wire although possessing some serious defects has therefore been accepted as being much better than the other materials available for the purpose.

In standard construction, trolley wire is suspended in spans of 100 feet on straight lines and in shorter spans on curves, the distance depending upon the radius of the curve, local conditions, etc. These spans are supported by ears which vary in construction but for the most part depend upon a fixed mechanical grip of the wire. In the earlier construction, ears were soldered to the wire, a process which annealed the hard drawn copper with the consequent reduction in tensile strength, but this practice is now rapidly becoming obsolete. The wire, therefore, is subjected to the pull of its own weight, to the extraordinary stresses of ice and snow and to severe pounding from the trolley wheel. In addition the wheel passing along the wire gives to it a wave motion which proceeds along the wire until an ear or other fixed support is reached where the wave is suddenly checked with a consequent sharp upward bend, followed by a series of bending stresses diminishing in force as the wave motion dies out. On a busy line where cars are operated on a small headway, the wire is subjected to practically a continuous effect of this nature, and in addition to this must be capable of carrying a large amount of power in order to diminish the outlay in feed wire.

To give efficient service under the conditions above noted, trolley wire must possess the following qualities:—

First:—Conductivity.
Second:—Tensile strength.
Third:—Flexibility.
Fourth:—Homogeneity.
Fifth:—Toughness.

Each of these qualities is essential and no one of them can be increased beyond a certain point without a proportionate reduction in one or more of the others. For example, certain wires have been made from an alloy of copper and tin which have high tensile strength, great toughness and homogeneity, but are lacking in flexibility and have a conductivity only half that of pure copper. On the other hand, by proper drawing, wire can be made very homogeneous, flexible and tough, but lacking in tensile strength, the conductivity being unimpaired. To recapitulate, high conductivity is necessary for economical operations; tensile strength to withstand the abnormal loads; flexibility to enable stringing and to allow the wire to adjust itself under strains and blows; homogeneity that the stresses may be uniformly distributed along the wire and toughness to withstand kinking, wrenching and slow distortion, without giving way.

Attention naturally turns next to the methods of determining to what extent wire possesses these essential properties. The determination of conductivity is very readily and accurately made with a Wheatstone Bridge or one of the several appliances based upon the same principles which are especially adapted for trolley wire. Tensile strength may be determined in a testing machine of suitable capacity, but owing to the nature of copper the elastic limit cannot be determined by a drop of the beam, as the metal apparently yields quite steadily up to the breaking point. Numerous conflicting figures are in print regarding the yield point of copper but as a stress and strain diagram shows a nearly perfect curve, the actual elastic limit can only be accurately determined by applying increasing loads for a definite length of time and measuring the permanent set in each case. Such a procedure is obviously too complicated for commercial testing, so that the elasticity of the wire has to be judged by other means. Under ordinary circumstances, power to resist the effects of twisting is not necessary for conducting wire, but the torsional strength measures indirectly but accurately two of the most important mechanical properties that a wire can possess, namely, homogeneity and toughness. In a tensile strength test the maximum tensile load is largely a factor of the cross-sectional area and the amount of work which has been put into the hardening of the surface. This test will detect inferior drawing or inherent weakness of the copper but it gives no idea of the power of the wire to resist distortion, nor of defects such as oxide seams which run lengthwise of the wire, and do not have a cross sectional area of sufficient sizes to affect the breaking strength. Under a torsional strain, however, such defects are quickly noted. If the wire contains an oxide seam as above spoken of, the twisting will open it up and at once weaken the strength of the wire. If the wire is of unequal hardness, the twists will tend to bunch up in the softest portion and very noticeably show this spot. Inferior copper not only shows a very low number of turns but splinters and slivers of metal appear on the surface which in very bad wires fall off to such an extent that a paper held beneath the sample during torsion will show a considerable collection of copper fragments. Non-homogeneous copper, due either to impure metal or uneven drawing, will show a great difference in the

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