the value of water transportation; and although it may seem visionary, it is not improbable that the engineer will yet accomplish the desired result of transferring large vessels from the lakes to tide-level. A region which has developed so many surprises could well afford to add this to the list. In fact, an International Deepwaterways Commission is now organized to consider such projects.

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RETURN CIRCUITS OF ELECTRIC RAILWAYS.

BY CHARLES HEWITT.

Electric traction began its rapid progress in the year 1887. The first roads, with the exception of that in Richmond, were mostly suburban lines, or were located in the smaller cities. It was not until the larger cities began to adopt electric traction that the electrolysis of iron pipes began to show itself; not until the summer of 1891 did this trouble take any definite shape.

The Erie Motor Company, Erie, Pa., experienced much trouble with the water pipes in its station; the company also had complaints from the plumbers in town that the service pipes were rapidly being corroded. I made an examination of this plant and others in Pennsylvania, and found a very bad state of affairs. At that time it was not definitely known that the trouble was due to electrolysis; in fact, as most of the trouble was confined to the station, it was supposed that the trouble was due to bad feed-water. I found rail bonding very poor. In some places there were no bonds at all. I also found the positive pole connected to the pipes and track, the negative pole being connected to the trolley wire. At that time a considerable number of roads were connected in this manner. On investigation I found that 40 per cent. of the total output of the station was carried by the pipes, and it was soon very evident to me that the trouble was an electrical one, pure and simple.

In the course of a few months various notes began to be published in the different papers in regard to trouble with water pipes; but it was not until Mr. Farnum, of Boston, read his paper before the American Institute of Electrical Engineers that the trouble was placed before the public in any precise form, although it was well understood by the companies manufacturing railway apparatus for months previous. From that time to the present, much has been written and many suggestions made, and a large amount of data collected, so that at the present time I believe we are in shape to contend fairly with the disease.

In considering this subject it will be well, in the first place, to inquire what causes electrolysis, and why are we troubled by it. Various explanations have been given, and I must confess that at the present time I am not able to answer the question positively. One thing is certain, namely, that it takes place more rapidly in salty earth than in dry sandy soil. Copper return wires in dry sand have remained apparently unaffected for years; whereas, similar wires buried in the soil of Salt Lake City will scarcely last three months. In the case at Erie, previously cited, much of the trouble was in water pipes which were suspended in the air and showed the corrosion on the inside. Whether the corrosion was due to nascent gases or to the decomposition of salts, I am not prepared to state; it seems evident, however, that moisture in some form is necessary to cause the trouble, and I believe that the most destructive element is the nascent oxygen. Our text books, however, say that it takes a pressure of nearly 2 volts (1.47 Gore) to decompose water; whereas, Prof. Jackson has proved conclusively that a mere directive force is all that is necessary to cause electrolysis; and to my knowledge electrolysis has very rapidly taken place under pressure of less than 1 volt.

The electrolytic action is quite characteristic and is very easily distinguished from ordinary corrosion. You will see by the samples here exhibited that there is a decided pitting of the surface of the metal, whereas the corrosion of an ordinary rusted pipe is of a fairly uniform character. This pitting, I presume, is due to the fact that

the metal is not perfectly homogeneous, and that the purer iron is the most readily attacked.

It is somewhat amusing, at the present day, to recall the fact that, in the year 1887, the earth and rail-return were considered as zero resistance; we know, at the present day, that this is so far from the fact, that the rail-return problem is one of quite as great importance as the feeder problem.

Now, why does electrolysis bother us at all? In considering this, we must look upon rails and the pipes as two separate systems of conductors, which, in their normal condition, are slightly insulated from each other by a layer of earth. If, therefore, the track were of zero resistance, or the insulation between the track and the pipes were of infinite resistance, it is very obvious that no current would leave the rails and enter the pipes. Unfortunately, neither of the conditions can be perfectly realized. The actual conditions can be shown more clearly by *Fig. 1*. In this, for

FIG. 1.

simplicity's sake, we will assume a straight road with the station at one end, representing the track by the heavy straight line; we shall assume, also, that, between the far end and the power house, there is a drop of 10 volts. Now, with any such drop in the track, and with a system of piping below the track forming a fair conductor on account of the very mass of the material, it is very evident that some of the current will seek this path, and more or less will be thus diverted in proportion to the drop in the rail.

Referring again to *Fig. 1*, I have endeavored to show the condition of the pipe in reference to that of the track by the curved line. At the outer end it is very evident that the potential difference between the rail and the pipes would be a maximum, assuming, of course, that the trolley wire is positive, and that the current is flowing towards the station. This difference in potential will gradually decrease as we approach the station, until we reach a point where

the drop in the track and the drop in the pipe, together with the resistance between rail and pipe, combine to form a neutral point; from this point out there can be no electrolysis of the pipes (except at local points); but as we approach near to the station, the potential of the pipe begins to rise above that of the track, and it is just here that we may begin to look for trouble.

The electrolytic action takes place only at the anode or positive pole. The region between the station and neutral point we will call the danger area, and our sole concern is to protect the pipes in this region. Now, how shall this be done? It is very obvious at the outset that we must straighten out the curved line in *Fig. 1*. In other words, we must make the pipe negative to the rail at all points.

FIG. 2.

So far, I have assumed that no connections have been made between the rail and the pipe. Many engineers have recommended the connecting of the pipes and the rail-return, and I believe there are to-day advocates of this scheme, but, to my mind, the suggestion is utterly preposterous. Why aggravate our trouble by inviting currents into the pipe, when we have sufficient trouble from the currents which enter the pipes uninvited? Ordinary gas and water pipes have not been laid with the view of being utilized as electrical conductors; they become good conductors simply from the very mass of iron of which they are composed. The joints, however, are anything but perfect metallic unions, and although these may transmit small currents with impunity, if we force larger currents through the pipes, we will get a drop at the joint, which will give

us a condition shown in *Fig. 2*, in which the drop in the joint is supposed to be sufficient to overcome the resistance of the earth around the joint and cause some of the current to flow around the outside. This condition, as you will see, will cause a local danger point at one side of the joint. To me it seems just as reprehensible on the part of a railway company to appropriate the pipes of the water and gas companies as an annex to their system, as it would be to appropriate the conductors of another electric company.

The position of the engineer is now very clear, and may be stated as follows: Do not invite current into the pipes, but take care of all that comes in uninvited; in other words, keep pipes and return system as distinct from each other as possible, and make the resistance of the track system as low as possible.

We are now in a position to take up the various devices that have been suggested for overcoming the trouble. Naturally, our first consideration is a perfect rail bond. A 60-pound copper rail has a cross sectional area of 8.3 square inches, which, at the ratio of 7 to 1—which ratio is the one usually given for the conductivity of iron and copper—would be equivalent to a conductor of 1,500,000 circular mills. Since, however, our rails are made of comparatively high-carbon steel, I am inclined to think that the true ratio is nearer 10 to 1, which would make the rail equivalent to a bar of 1,050,000 circular mills copper.

When we realize that there are two rails in each track, and that all the ramifying tracks in a large city like this are connected together, we begin to realize what an immense mass of electrical conductors the tracks present. It would be very injudicious, therefore, and a needless expense to abandon the tracks as conductors.

Mr. J. H. Vail advocates the use of the return feeders to an extent which practically eliminates the track as a conductor, and I believe he has patented a system of track feeders which is the counterpart of the ordinary system of feeders used in lighting and railway work; and he proceeds to figure the drop in the return feeders in the same manner that he would figure the drop in the positive

feeders, eliminating the track from consideration. A system of this kind is needlessly expensive, for reasons which I have already shown. If the track be well bonded there is no necessity for an elaborate system of track feeders. In some of the smaller roads, no track feeders whatsoever are necessary; in the larger roads, such as we have in this city, there are many places where the current density becomes so great that it is advisable to augment the track by the addition of a proper amount of copper; in fact, all track in the city should be protected by a smaller or greater amount of copper, in order to guard against broken bonds, as well as to provide a better conductor.

A modification of the Vail system of track feeders consists in running a copper cable or bar in a trough filled with insulating material and parallel to the track. This conductor should decrease in size as it gets farther away from the station. There is no doubt in my mind of the advisability, in all cases, of protecting the return cable with a moderate amount of insulation. Experience has proved, time and time again, that an unprotected copper conductor laid between the rails is very liable to be reduced to a state of "innocuous desuetude" by the very action it is intended to prevent.

Both of the above-described systems of return feeders will reduce the liability to injury to the pipes, but will not entirely prevent it; in other words, unless the copper is infinite in amount, we will still have a danger area in the vicinity of the power station. Our care, therefore, should be to provide an amount of copper for the return which shall be in accordance with the demands of each individual road; and, in addition, we must provide a means of protecting the pipes within the danger area. The first, and, perhaps to the present day, the best, suggestion which has been made was that presented by Mr. Farnum, in the paper previously cited. This consists in running one or more return feeders to all the pipes which show a potential positive to the track or return cables. This return feeder must have no direct connection with the other return feeders, except at the negative bus bar, and must be of sufficiently

low resistance to bring the potential of the pipes at least down to that of the tracks at each point between the power house and the danger line.

I am well aware that, in many cities, the track bonding is very inferior, and also that the tracks have been bonded to the pipes. Both of these will aggravate the difficulty of reducing the potential of the pipes by the separate return feeders; but if the road be well bonded and no connections have been made between pipe and rail, the matter becomes quite easy of solution. I have been informed by the very highest authority that, of the output of 8,000 ampères in one of our Eastern cities, 5,000 ampères is returned by the pipes. Is it any wonder that the city authorities object? In contrast to this, in three stations in this city, which I have personally tested, I find that, in a station with an output of 3,000 ampères, the maximum returned by the pipes was 50 ampères, or $\frac{1}{60}$ of the total output. In the other two stations the ratio between the output and the main return by the pipes was practically the same, namely, $\frac{1}{60}$ of the total output. You will readily see that we have here a much easier problem to handle.

One of the most recent methods of reducing the potential of the pipe below that of the rail has been suggested by Mr. Harold P. Brown, and has been very widely advertised by magazine articles and otherwise. This plan is to connect the negative lead of one generator to the pipe system in the station, and to run this generator at a greater difference of potential between its leads than between the negative bus bar. Mr. Brown, in a recent article in *Cassier's Magazine*, has claimed, by the use of this system, to have made a reduction in the output of the power station in Newark of 300 horse-power. It seems to me that this plan is radically at fault; for, even taking no account of the difficulties of running a special generator for this purpose, it is self-evident that all the current generated must be returned through the pipes, and, to my mind, it is absolutely wrong to compel a single ampère of current to enter the pipes; our efforts should rather be in the opposite direction. The complications necessary for using the double ground on our

machines, of giving up one machine for this special purpose, or even of installing a separate machine to do this work, will be apparent to every one.

A modification of this plan, however, and which, I believe, has never been publicly advocated, has occurred to me, namely, the application of what might be termed an inverted booster. Assuming that we have a separate set of pipe return feeders, and that in this feeder, before attaching it to the negative bus bar, we place a series dynamo which shall have a current capacity equal to the amount of current returned by the pipes, and a potential only sufficient to overcome the maximum difference of potential between the pipes and the track. This generator will have a tendency, then, to lower the potential of the pipes below that of the negative bus bar, and, being of very low potential, it need only be a very small machine. For instance, in the station above referred to, where the maximum current returned by the pipes was 50 ampères, the maximum difference of potential was also found to be less than 1 volt; if, therefore, we put in a generator of say 100 ampères capacity and 5 volts, we have a machine of only $\frac{1}{2}$ kilowatt, which could readily be run by a 1 horse-power motor. You see how small a machine this plan demands. It would be automatic in its action, inexpensive and easily installed, and I believe would give absolute protection to the pipes. In cases such as those stated above, where the current returned by the pipes is abnormal, it would be necessary to put the rail-return system in proper shape, and then use the booster as a final refinement.