a high resistance compared with iron pipes that they are practically insulating.

Bonding of pipes to the rails or to the negative return circuit can only afford local protection to the extent that the piping connected forms a continuous metallic conductor, and this latter is an unknown and indeterminate quantity in a piping network. In the practical working out of a bonding or drainage system two opposing tendencies develop; first, there is a reduction in the difference of potential between pipes and rails in the positive areas, and consequent reduction of damage in those areas; and, second, there is an increase of current flow on the pipes throughout the entire system, thus increasing the danger of trouble at high resistance joints, or other places where two piping systems or separate portions of the same system are electrically discontinuous. As a rule, in the early stages of this system, and especially in small networks when there are comparatively few bond connections, and the resistances of the paths over the pipes are, therefore, relatively high, the effect is apt to be beneficial, reducing the danger in positive areas more than it increases the danger elsewhere. As the system grows and the load increases, more and heavier bonds become necessary. The current on the pipes may finally become so great that the trouble from current shunting around joints, or between separate systems, will increase more rapidly than the danger in the positive areas is reduced, and any further increase in the bonding becomes an actual source of danger to the system. Since bonding transfers the trouble from the region where it was most evident to a new locality where it may require several years to manifest itself, the false impression is created that the trouble has been removed. It is due largely to this obscure manner in which trouble develops that has caused this method to become quite widely used. A number of cases have, in fact, been reported where a main bonded to the negative return circuit at the power station was completely destroyed by electrolysis a block or two away, because of a high resistance joint in the main forcing current to shunt around the joint and leave the main a short distance away from the power station. A case of this kind is illustrated in Fig. 14. In another case, the water main on one side of the street was bonded to the negative return circuit at the power station, and a main on the opposite side of the same street, although connected through cross-piping to

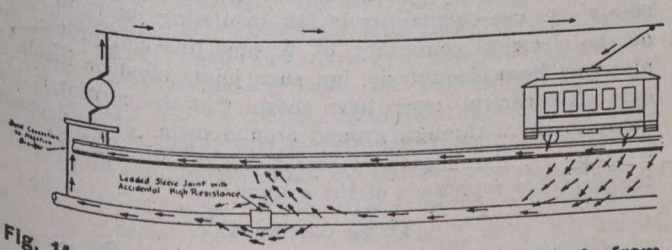

Fig. 14.—Showing Increased Danger from Electrolysis from Bonding Pipe to Rails, Caused by Accidental High Resistance Joint in Pipe.

the bonded main, was completely destroyed because high resistance joints had developed in the connecting pipes.

Among the methods which have been used to minimize the escape of currents on systems using the grounded rails for the return conductor are increasing the resistance between rails and ground, increasing the resistance between pipes and ground, increasing the resistance along the line of the pipe by means of high resistance joints and decreasing the drop in potential in the grounded rails.

The resistance between rails and ground can often be increased by using broken stone ballast, whereby the rails are kept out of contact with ground, and water is allowed to trickle away from the rails, thereby maintaining high resistance between the rails and ground. Where an electric railway owns its own right-of-way, it is frequently feasible, as already stated, to practically insulate the rails from ground.

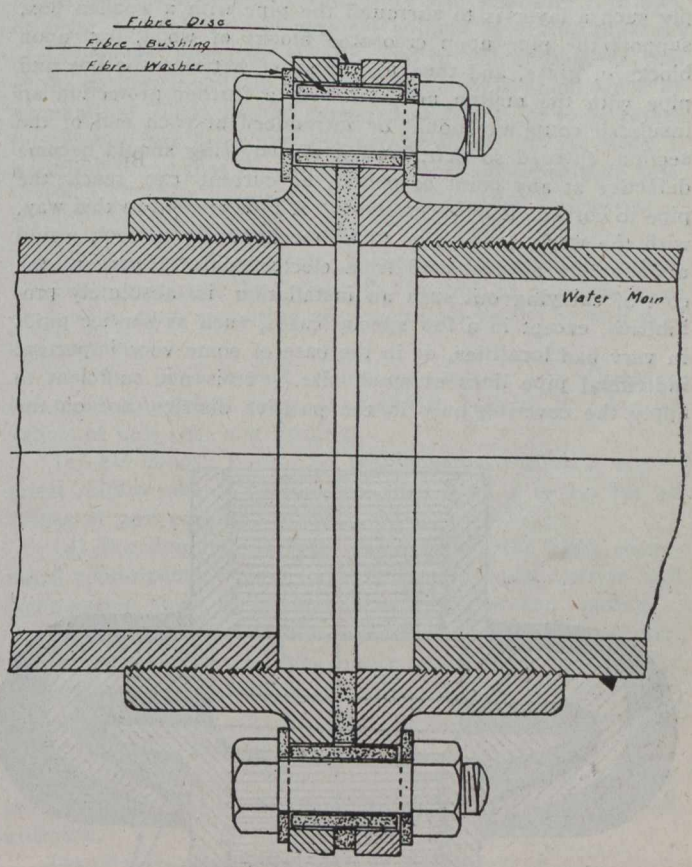

Fig. 15.—Section of Macallen Insulating Joint for Service Pipe.

Attempts have been made to insulate pipes from ground by paints, dips and insulating coverings. Experience, as well as a large number of tests on such paints and dips have, however, shown that no dip or paint will protect a pipe against electrolysis in wet soil. The first difficulty is the mechanical one of applying the paint so as to form an absolutely perfect coating, and then to prevent mechanical damage to the coating. Where imperfections exist or develop aggravated trouble always ensues. Experience further shows that, even where paints or dips are apparently intact and perfect, electrolytic action is not prevented; and, in fact, very serious electrolytic pittings have been found under apparently good coatings. It has been found that in most cases the coatings applied have either been completely destroyed by the effects of the wet soil and the electric currents, or defects in the coating have developed causing concentrated corrosion at such defective spots. The destruction of paints in wet soil, where subjected to an electric current, is due to traces of moisture finding their way through the coating, giving rise to the flow of a feeble current and resulting in a very slight amount of electrolysis. The gas and other products of electrolysis then form blisters and finally rupture the coating. Pipes in positive districts covered with imperfect insulating coatings, are in greater danger from electrolysis than bare pipes. Coating pipes in negative districts with insulating covering does some good in reducing the amount of stray current which reaches the pipes. Where it is attempted to apply a heated material, like pitch or as-