

DISCUSSION ON "THE APPLICATION OF PORCELAIN TO STRAIN INSULATORS" AND "ELECTRIC RAILWAY CATENARY CONSTRUCTION", NEW YORK, MAY 27, 1910.

**Percy H. Thomas:** Mr. Kempton's paper gives us some actual tests on porcelain. We have had almost no data hitherto on the mechanical qualities of porcelain, quantitatively speaking. The manufacture of porcelain has been a secret, a mystery, and engineers have taken what was offered by the makers, taking the catalogues and selecting the best design for their purpose among those offered.

We here have a beginning of figures on the compressive, tension and other strength of porcelain as a material, some of the same sort of data as we have on steel and wood.

The compression strength of high grade porcelain is relatively very great, 16,000 lb. or thereabout. The average shearing stress here is given as 2400 lb. per sq. in., and the tensile strength as 650 lb.

This relationship between the various sorts of strength in this material dominates the form of design. We are very familiar with the shapes of insulators shown in the paper. There is one example among those of an important type of insulator in which is used the weakest quality of porcelain, and that is the suspension type of insulator, similar to Fig. 9 of the paper. This is a matter of which we should think pretty carefully.

I want to make a suggestion in connection with Fig. 9. That insulator shows porcelain in tension, as this design is made, and as the failure under test is described this insulator had better be made in some different proportion.

As shown in the paper we have a fracture at the bottom of the cap, that is across from the top of the inside pin to the bottom of the outside cap. The result is then only the tensile strength of the porcelain is utilized. If on the other hand, the insulator had been shaped differently, the pin being carried well up inside, with a deep metal cap taking hold well down on the insulator, since the pin cannot pull out without crushing the porcelain.

These tests, while they give some numerical figures are faulty in one particular. Mr. Kempton has apparently taken some insulators which he had at hand for making tests, and these show numerical results for those particular forms; but in no case are the tests such as to give us a clear knowledge of the materials as materials. Some of the insulators broke at the edge. In Fig. 3, the shearing test, there must be some tendency to split the insulator as shown; perhaps not much, but enough to render this data uncertain.

I remember some tests on one of these suspension types of strain insulators, such as No. 9, which gave a tension strain, roughly two or three times as great as Mr. Kempton has given. Possibly Mr. Kempton can say something on this subject at the end of the discussion.

There is another point which should be determined further by tests before any final conclusion is reached, and that is whether materials made by different manufacturers and materials of different compositions and treatment, will show the same unit of strength?

This would be an admirable thesis for some post-graduate work at a university or college. It is difficult for engineers in general practice to make a careful general study.

We seem in the matter of insulators to be arriving at the condition which finally comes in all new classes of work. At first designs are on the hit or miss principle but finally after sufficient investigation, reliance is made on a few of the old simple, practical, fundamental laws. For example, it is an old principle to take account of unequal expansion. The cementing in of metal pins in the strain insulator, may lead to trouble where expansion is serious. Again, if you do not allow for differences of flexibility in different materials, there is a strain on the porcelain. These matters are easily overlooked, but they are the simple principles that should have been borne in mind from the beginning.

It is often suggested that the way to get reliability in insulation, is to increase the margin of safety. This can be done quite easily in overhead railroad work where the trolley voltages are low; by choosing a factor of safety of five instead of perhaps three. This, however, is not very possible at 100,000 volts or even at 60,000 volts. Where feasible is thus possible to gain superiority and reliability at only small additional expense.

I ask Mr. Kempton a question: It is well established that a high tension porcelain insulator, 60,000-volt petticoat type, can be *shattered* by a lightning stroke without the puncture of the material, and without any arc following from the generator. This seems to be caused by something in the nature of a mechanical shock. The result is often the dropping off of the outer petticoat, it being broken close to the stem of the insulator.

I also ask Mr. Kempton if he has any suggestion to meet this condition. The phenomenon is reported at the Taylor's Falls system, and on the Ontario Power system. These are two thoroughly authentic instances. How can this strain be resisted?

Considering Mr. Smith's valuable paper, I would like to have his opinion as to the practicability of obtaining sparkless action in pantagraph trolleys by having a relatively light piece on the top of the pantagraph which shall have the least possible inertia. The heavy arms would then not be required to follow every slight movement of the sliding contact.

**C. J. Hixson:** It has been most interesting to have Mr. Smith trace the development of the catenary construction and listen to his comments and descriptions of the various devices used in connection with the same.

It has been stated that catenary construction was first brought

out in 1904. In 1903 while connected with the Allgemeine Elektrizitäts Gesellschaft, of Berlin I remember discussing and inspecting with visiting Westinghouse engineers, the catenary line installed by the Union Elektrizitäts Gesellschaft upon a branch of the State Railway known as the Nieder Schonweide-Spindlersfeld line. In October of the same year, the *Street Railway Journal* published an illustrated article describing the installation. I have no doubt Mr. Smith meant, that it was first used in this country at that time.

In Mr. Smith's comments regarding catenary developments abroad, and the improvements upon the New Haven System, as well as the experimental line of the Connecticut Company, he states there is a general feeling of satisfaction with these constructions. It is significant that all of these have a more or less flexible trolley wire.

This vertical flexibility of the trolley wire is, it seems to me, the keynote to the successful collection of current from a trolley wire.

The general conditions of stability and of sidewise anchorage, limit the vertical flexibility to a few inches, and it is necessary to assist this flexibility by frequent supports or hangers

The height of the wave in the trolley wire as the collector passes along should be such as to take up all the sag between hangers and still raise the hanger a couple of inches as it passes under it.

The lifting of the hanger to a floating position eliminates the blow that would be delivered to a rigid support. Catenary hangers rigidly connected become increasingly hard as the bracket arm is approached. With a flexible hanger the increased and ever present flexibility at the point of contact, compensates in a measure for the inherent sluggishness of the roller pantagraph so complementarily referred to in the latter part of Mr. Smith's paper.

For very heavy currents with two trolley wires side by side vertical flexibility is of great assistance in keeping the necessary contact pressure down to a modest figure and yet maintaining continuous contact with both wires at all times.

In order to have vertical flexibility the strain in the trolley wire should be moderate say from 1200 to 1500 lb. With this tension, with hangers 13 feet apart and with a No. 4/0 trolley wire, a vertical flexibility of an inch or so can be attained with an upward pressure of about 7 lb. This reduced tension in the trolley reduces the strain upon pull-offs, anchorages, strain insulators, and the line in general, thereby decreasing the original cost and the cost of maintenance.

In order to maintain the tension between reasonable limits at different temperatures provisions should be made for taking up the slack without disturbing the hangers and pull-offs.

The trolley wire is held best on curves by frequent pull-offs. This gives maximum flexibility with low stresses and moderately

strong strain insulators. On earlier installation steady braces were used, but they have now been superseded by either flexible pull-offs or line steadiers. A steady brace when used as a strut gives a hard spot in the trolley wire.

Regarding pole spacing on curves, the table given is, we assume, designed to be used with no other points of pull-off than a steady brace at each pole. It is possible to maintain this same offset of the trolley wire from the center of track and use a longer pole spacing by running a back bone and using more pull-offs. This also makes a more flexible construction. If the curve happens to be on the side away from the pole line, a bracket extension can be used to support the backbone.

In conclusion it might be said that a single messenger flexible catenary has been in successful operation for the past two years upon the Saratoga Division of the Schenectady Railway. There has been no sign of wearing the galvanizing on the messenger wire due to the movement of the loop, as the sides of the same seldom if ever more than just touch the messenger wire.

**R. D. Coombs:** Before attempting to say anything about the experiments made by the Pennsylvania Tunnel and Terminal Railroad about two years ago, I might call attention to a few general facts, or rather, general considerations.

Since the track on which the equipment runs is not a plane, but a series of vertical curves, I think that it is entirely unnecessary to attempt to keep the trolley wire perfectly horizontal. The equipment will not run in a plane, and so I cannot see why it is necessary to keep the trolley wire in a plane. That is aside from the fact that you cannot do it.

The question of flexibility is as yet very uncertain. The Germans have used a secondary catenary, and according to their statement it is entirely successful, but their speeds and train-loads are less than our own. The experiments to which I referred a moment ago seem to indicate that a single catenary with a very light hanger, composed of a flat section,  $1\frac{1}{8}$  in. by  $\frac{3}{16}$  in., looped over the messenger, and with the ordinary type of ear, was about as successful during the limited range of those experiments, as the German type with the auxiliary catenary. I am inclined to believe that a light hanger particularly in conjunction with a trolley wire having considerable stiffness and strength, possibly a steel trolley wire, as I believe was used on part of the New Haven installation, with either a copper messenger or copper feed wire to provide the necessary conductivity, would be a combination worth very careful investigation, and perhaps some experimentation.

The little hanger which loops over the secondary wire and attaches to the trolley wire, permits vertical movement, but seems to have a tendency to roll. On a portion of the experimental line, in putting up the trolley wire, it was found that the trolley wire had a twist or roll in it; and that the little hanger above the ear rolled laterally, and became to a certain extent,

bound, particularly at a pull-off. That same criticism, it seems to me, would apply to one of the figures in Mr. Smith's paper. I refer to Fig. 27. I should expect that inclined hanger, which is the same as a pull-off in effect, to roll, and I ask Mr. Smith whether that tendency has been experienced?

I am rather inclined to question whether it is necessary to pull the trolley wire to an excessive tension; and I believe that to be a subject which requires more investigation. I think the rigidity, and the tension of the trolley wire, the rigidity of the catenary above the trolley wire, and the flexibility or "intelligence" of the pantagraph should all be considered together; and that the failure of no one of them should be allowed to prejudice the particular arrangement of design.

Until these features are all brought into a harmonious relationship, no single arrangement can be termed satisfactory. The pantagraph has always seemed to me to be a suitable field for experiments, and it should be noted that the secondary flapper, according to the statements of the German engineers, has given entire satisfaction abroad.

Director Freishmuth of one of the German companies, told me on his visit to this country about two years ago, that their auxiliary arrangement on top of the pantagraph, gave entire satisfaction, and that it did not spark. Their speeds are less than ours, and I believe their train-loads are also less; but if these pantagraphs have given the satisfaction abroad which it is claimed they have given, it would certainly seem that the pantagraph is a field for further experimentation and improvement.

Fig. 14 shows the messenger wire broken at each support, that is, each span, is a unit in itself, the advantage of which Mr. Smith questioned. I believe one reason is that the short span can be assembled on the ground, the hangers placed, and the end socket can be done either on the ground or in a convenient shop. It does not require an aerial operation.

The combination of the steel trolley wire and the copper messenger is in use on the New Haven and it was to be tried on the experimental line. It was not installed, but it was because of no lack of faith in it as a device. I believe the grease from the pantagraph shoes, or a system of greasing the trolley wire will prevent any rust.

The loop, attaching the hanger to the messenger wire, in case a loop is used, should be properly fitted at the top in order to allow the hanger to be vertical.

I do not think I can add anything in a very definite way, insofar as the results of the experimental line are concerned. It was necessary to put up comparatively short sections of different types of supports, different types of suspension, and different types of catenary. And as a result there was not a sufficient length of any one type to produce a determinative test. The locomotives passed rapidly from one section to another and it was almost impossible to ascertain on which section the

wear of the pantagraph shoe occurred. The relative wear could only be inferred by observation of the action of the pantagraph on a given section. At the same time it was possible by observing the action of the different types, to determine with more or less accuracy, a certain degree of relative merit.

The experiments did not continue through a round of seasonal changes, and definite results were not obtained, but I am inclined to question whether on long spans, there is any objectionable action due to the tensional changes. The German construction, with the tension devices by which the wires are automatically kept at a certain tension by weights at the supports, were used, but no definite results were obtained. We obtained just as satisfactory service on sections where the device was not present.

**R. C. Thurston:** During a high wind and from the rolling of the car, unless the wires are in ideal condition, there is a good deal of slack wire, which will cause the trolley or the pantagraph to go to one side and dip, and while over, allow the ends of the shoe to hit the cross arm. If the wire was perfectly tight, this would not happen. When our road was first installed, we had no such trouble, but after the heat of summer and the cold of winter had expanded and contracted the wire, there was slack. But owing to the expense and the lack of time between trains, it is not always advisable to pull a slack wire tight.

The spacing rods are clamped tight to the messenger wires. I believe there should be a loop at the top of the spacing rod to allow the spacing rod to slide along the messenger wire, as the slack in the trolley wire would not then form the kinks in the trolley wire that it does now.

We have had several bad cases of brakes in the copper wire and the brake is not sudden, we found it to be an old fracture, which was probably caused by the pounding of the shoe. As these breaks do not occur in cold weather, it shows they were not from contraction of the wire through cold. The break is always formed after the car has passed over, and it always caused us to put a splice in the wire.

**Chas. R. Harte:** It is too often forgotten that the overhead construction of an electric railroad serves in two capacities.

As a conductor by which energy is transferred from the central station to the collecting device of the motor its function is simple and well understood; that it is also the track upon which the collector travels at high speed is a fact too frequently ignored, although it is in this latter capacity that practically all of the serious problems and difficulties arise.

In the case of a railroad, light rails laid on soft ground, where a marked displacement wave precedes the train, will, within their load capacity, give as smooth riding, and will require as little maintenance as the hundred pound rail on stone ballast as unyielding as possible. But if in either class of track there is permitted to occur a spot of opposite nature, so that there is

an abrupt change in the character of the displacement wave, there immediately follows rapid wear and serious injury.

Precisely the same results are manifested under similar conditions of the overhead; a hard point in an otherwise flexible line, or yielding spots in a rigid trolley at once develop kinks, crystallization occurs, and presently the wire breaks.

Up to the present time developments have indicated that the flexible line is easier of attainment than the rigid type; the writer believes, however, that the possibilities of the rigid construction have been by no means exhausted, and hopes to see further experiment in that direction.

The unfavorable condition is that in which whatever the cause, the trolley wire tends to bend on a short radius. In the earlier lines the comparatively large sag gave a large intersection angle at the points of support, and the clips being straight and short caused kinks in the line, in passing which the collector tended to momentarily reverse the bend on the approach side, and to deliver a sharp blow against the opposite side. The supposed necessity of eliminating the large sag led to the development of the catenary construction, as pointed out by the author. But, and this would seem to be the point urged by Mr. R. D. Coombs in his discussion of Mr. Smith's paper, a truly straight trolley wire is by no means a necessity. It is not the amount of the intersection angle at directional changes, but rather the shortness of radius of the enclosed curve that causes injury. With a long radius bend, and a type of support which would either gradually damp out the displacement wave or would transmit it without material interference, a heavily sagged trolley ought to give excellent service under severest conditions. Such a type of suspension, employing spans of two hundred and forty feet with a sag of thirty inches, the wire being carried in a curved ear of special design and some forty-four inches long, has been proposed by Mr. Joseph Mayer, Consulting Engineer (see *Transactions American Society of Civil Engineers*, Volume LXI, page 5) but so far as the writer is aware, has never been actually tried out.

The author, in describing double catenary construction says: "The excessive rigidity of this type has been found undesirable in practical operation". As an unconditional statement this is open to question. It is quite true that the first installation of this type to receive a thorough tryout was not entirely satisfactory, but the difficulty arose from the fact that while the hangers were very rigid, the line between yielded. At the critical speed the resultant chatter of the collector became synchronous with its period of vibration, and the line received severe punishment from the heavy blows of the pantagraph, in addition to the tendency to crystallization from bend reversals. The difficulty was most successfully overcome by duplexing the trolley, attaching the lower wire to the old trolley only at the centers of the secondary spans, but it is at least open to question if equally

good results would not have obtained had the line been made uniformly rigid by the use of a tee or similar stiff section attached to the hangers.

As pointed out by the author, the question of the side clearances of poles is very important on electrifications and particularly so on railroads with black signals. Eight feet from center of track to face of pole brings the latter practically in line with the signal mast in its usual position and the engineer or motorman is hedged by an apparently solid wall of poles, behind which except as it is very near, nothing can be seen. Certain types of signal employ a centrally pivoted blade, half being in front of the mast, to obviate this difficulty of sighting, but even for this, ten feet clearance from track center to face of pole is little enough.

The author's conclusion that the trolley wire should very closely follow the center line of the track will have the endorsement of practically all operating men, particularly if qualified by the further proposition that for wheel work the center of track is to be considered projected through the center line of the car, in order to meet the offsetting of the wheel by the super elevation of the rail. This same offsetting affects the lengths of brackets on curves particularly if the poles are on the outside, in which case the bracket bar will often have to be materially longer than the standard.

Operating men generally will further agree with Mr. Smith that the irregular and unavoidable cross motion of the shoe, due to various car movements and sways, entirely obviates the necessity—and most undesirable complication—of staggering the trolley wire to prevent localized wear on the collector.

To secure the desired alignment on curves the preference of the writer is with the method by bridle between poles, from which are taken equidistant pull offs. It is of course desirable to maintain this backbone dead, but on light curves the weight of the insulators is apt to cause sags which may prove troublesome. This can be helped by placing the insulators at the bridle, in which case of course the pull off itself is alive. In at least one instance the pull-off, of a single piece of seven strand steel rope, was unlayed for the proper distance, three strands going to the messenger, three to the trolley, while the seventh, whipped on the main portion, prevented further unlaying.

There seems to be little actual knowledge as to the comparative values of various types of catenary detail. In the matter of brackets the author expresses a preference for the three part pole collar as the method of attaching the over support rod to the pole. This is a point needing further investigation. The practice of passing the over support rod through a hole in the pole offers opportunity for decay to start, and weakens the pole slightly; on the other hand it has been the writer's experience that the pole collar, unless crushed into the pole, with consequent liability to decay troubles, is apt to slip and lower the

end of the bracket. The connection at the bracket end of the over support should also be positive; collars held by a set screw are prone to work loose and make trouble. As to bracket bar, the compound types offer greater attachment facilities, but are presumably more subject to corrosion. Devices at the pole end which permit lateral swing in case of unbalanced pull in the trolley save the bracket in case of heavy strain, as in the case of a broken wire, but the overhead is seriously slacked off for a number of poles each way; with rigid pole connection the brackets nearest the break are apt to be badly crippled if not ruined, but the area of disturbance is much less, a factor of great operating importance. The forms which split and take the pole between the members will stand very severe punishment from a trolley pole that has jumped the wire; socket pole connections, unless pinned or otherwise secured, are very apt to be shaken apart or broken under the same conditions.

As pointed out by the author, the matter of proper tension in the wire is complicated by the fact that conditions preventing excessive sag at high temperature result in very high stresses at low temperatures. How closely these stresses may approach the actual breaking strength of the wire is not always realized. Grooved 4/0 copper trolley is usually credited by the handbooks with a breaking strength of from 8000 to 8400 lb. A series of tests made by the writer, however on commercial stock samples gave a maximum of barely 7100 lb. on the unbrazed portion, with an average at brazes of 5600 lb., two samples failing below 5000 lb. (see Transactions, American Society of Civil Engineers Volume LX page 552).

While there are some differences as to detail commercial trolley wire is in general made from a "wire bar" of rectangular section, which is first rolled down to a round rod and then is finished by drawing. Brazing usually is done just before drawing, and in the samples tested it was evident that the latter treatment was not sufficient to overcome the local annealing at the surfaces of the braze.

The tension is properly dependent upon the nature of the overhead. If hangers are rigid the line between should be given equivalent vertical stiffness either by the form of cross section or by the tension; if hangers are yielding a much lower stress is permissible.

To secure an automatic adjustment the first Syracuse, Lake Shore, and Northern catenary had in the  $\frac{7}{8}$ -inch stranded steel messenger, at 20 deg. fahr. and for the standard span of three hundred feet, a sag of sixty-eight inches, but the trolley was a foot higher at the center of span than at the supporting bridges (see Transactions, American Society of Civil Engineers, Volume LX page 547). It was hoped this would minimize temperature troubles, but in the writers estimation its chief virtue lay in the fact that it materially stiffened the system against lateral sway. Later installations on this and allied lines have omitted this feature.

It is generally believed by users, that trolley wire could with advantage receive further treatment than is at present usual, for the market material of to-day certainly has decidedly less resistance to wear than the earlier output.

The writer is watching a working test of especially rolled wire which gives to 4/0 grooved copper an average breaking strength of practically 9000 lbs., but there has not elapsed sufficient time to permit any comment of value. The manufacturers, so far as the writer knows, have as yet set no commercial price on the treatment. Mr. T. H. Mather of the Syracuse Lake Shore, and Northern has for some time employed a wire which receives extra finishing treatment. The additional cost was, some time ago, about 6 per cent of the price of untreated wire; at that time Mr. Mather considered the resultant economy in maintenance and repair to be several times that figure.

But it is after all an illogical proceeding to impose the duty of resisting the abrasive action of the collector upon that member of the overhead which by nature is least adapted to resist wear, and functionally is most affected by loss of section, as is the case when the trolley wire is of copper. Phono electric and one or two other bronzes have for some time been used at points of unusually heavy wear, but the employment throughout of a trolley wire designed primarily to resist wear, as in the case of the Denver and Interurban's phono electric, and the New Haven's steel, is of very recent date. The author will doubtless be interested to know that his suggestion of a steel trolley and copper messenger has actually been in service for over a year. The trolley wire is identical in section with 4/0 grooved copper; the messenger is 19 strand bare copper wire cable sagged 24 inches for standard spans of 150 feet. This is on the experimental catenary section of the Connecticut Company's Hartford-Middletown line and the steel wire is continued for about half a mile beyond the catenary in simple suspension. At night the wheel has a bright tail of light but the actual wear in over a year's service is inappreciable, and this is also true of the messenger where it was feared the loops of the sliding hangers might cut the copper. This latter would indicate less danger to galvanizing on a steel messenger from sliding hangers than has been anticipated by some.

The Connecticut Company's experimental catenary has not had long enough service for final deductions as to the most desirable type of hangers, but indications to date seem to point to the old mechanical screw clamp ear with light hanger rod rigidly fastened to the ear, and looped over the messenger. The screws should be long enough to head up after the trolley is gripped; if this is properly done the type is at least as efficient as the more elaborate forms, and is far simpler. In this connection the author expresses a preference for "a nut screwing down on the lower end of the hanger rod, as in figure 24 as it can then never work off". In the writer's experience, while the nut

cannot escape, it has been found necessary for such types of hangers to be fitted with a locknut, as otherwise the main nut backs up to the rod enough to loosen the clamp and permit serious wear.

Rigid hangers require high trolley tension, and in case of relative movement of trolley and messenger are apt to come to grief; hinged types if jointed top and bottom and rigidly gripped to messenger allow relative movement and give a little flexibility that hardly seems commensurate with the complication. Bottom slide hangers seem unduly subject to wear, but have the marked advantage that the parts lifted are all of equal weight. The foreign sliding hanger lines have a secondary messenger of very slight sag and the loop hangers are all of equal length and weight; that satisfactory results were not obtained on certain American lines where hangers varied in length from four to twenty inches is hardly surprising. Long loop-hangers hinged at the ear have a tendency to tip when lifted, and sliding down the messenger lose their characteristic feature, and as a result of the shortened effective length, pick up the trolley.

Hangers with jaws closing symmetrically with reference to the rod will, within the limits of their capacity, take various wire sizes equally well; hangers in which the jaws do not so move however, while they have a small range, do not work well on sizes other than the one for which they were designed. For shoe work the contour of the jaws is of less importance; for wheel work it is essential that the jaws give good clearance lines, or, particularly on curves they will be badly pounded.

The matter of hanger spacing is one on which is needed much practical information—in fact this need of much practical information is characteristic of the entire subject of overhead construction. On a forty-mile-per-hour installation for wheel operation, with main spans of one hundred and fifty feet, excellent results are being had with a secondary spacing of ten feet, and barely twenty miles away equally good results are obtained on an installation identical except that the secondary spacing is fifty feet. It is the general impression that for shoe work the secondary spans should be very short; the writer knows of no installation on which long secondaries have actually been tried out, but it would seem that the manifest economy, if the number of hangers can be materially reduced without impairing the efficiency, warrants careful investigation.

The author touches a point of great importance in construction in the matter of hanger rod lengths for various spans. Theoretically the sag of each span should be mathematically exact; practically unavoidable variations occur to an extent which warrants the small amount of "fudging" which may be necessary to adopt standard span hangers to the shorter spans. The importance of reducing to a minimum the labor and the chance of error on the tower cars is best appreciated after a practical experience. In electrifying an operating steam road

the work trains lose from fifty to seventy-five per cent of their actual time, the lower figure being reached only under very favorable conditions; with much traffic on the line the time lost dodging trains may easily exceed the seventy-five per cent.

The author's point that strain insulators should under mechanical and electrical stress at the same time, is well taken, particularly where the strains are of the compression type where movement of the parts which in no ways affects the mechanical strength—in some cases actually increase it, due to better seating of parts—may completely destroy the insulating properties.

The difficulty of securing good strain insulators for high voltage work makes desirable the suspended bracket construction similar to that on the Rochester Terminal, and which employs a standard line insulator, in spite of the fact that its weight and area are decided draw backs, particularly in sections subject to sleet.

The author's hope that further investigations will be made in regard to roller types of collar will be shared by all who have investigated the subject and it is by no means impossible that a modification of the present form of trolley wheel may be of much value. The writer has for some time had in mind a shoe design in which the main pantagraph movement ranging through several feet should be effected by some positive mechanical device, probably a pneumatic cylinder, the air supply to be controlled by a sensitive contactor mounted on the main pantagraph. This contactor, having little inertia and therefore able to follow the wire almost instantly, would take care of variations within its range of about one foot each side of the middle point. The valves operating the main traversing device would open as soon as the contactor passed this mid point, and in most instances the response would be sufficiently rapid to keep the movements of the contactor within its limits. If, however, the depression or raise of the wire was so rapid that the main device did not attain the speed at which the change was occurring before the contactor reached its outer limit the conditions would be no different from those which at present obtain a very material portion of the time; on too rapid raise there would be an actual break in the contact; on too rapid depression the main traverse would be forced down by the overhead until its acceleration was equal to the rate of drop in the line.

**Ralph D. Mershon:** The author says that porcelain "can be moulded and worked into almost any desired form or size" This does not agree with my experience. I have designed insulators from time to time and endeavored to have them made out of porcelain. In some cases I have succeeded in having them made, and in some I have not. Not infrequently, where I did succeed, the price was prohibitive. As the result of the experience gained from such work in connection with a number of the insulator manufacturers of this country, I should say that porcelain, for insulators at least, can be practically moulded and worked into very few forms of limited size. The present

practical limit in thickness of porcelain of high dielectric strength is about  $\frac{5}{8}$  in. In some cases it is possible to get thicknesses of  $\frac{3}{4}$  in. of high dielectric strength, but such pieces are usually produced at very considerable expense, and their production is uncertain.

The author's investigations of the physical properties of porcelain are interesting, but might, with advantage, have been carried a good deal further. The porcelain he tested could hardly have been of the best quality as regards mechanical strength. The highest grade high-voltage porcelain made in this country will show a tensile strength of from 1,500 to 2,000 lb. per sq. in. and a compressive strength of approximately ten times this. These figures are the result of a great many tests made by myself and by others.

Of course, ceramic materials of all degrees of strength less than this are met with, but it is also possible to obtain material of greater strength. I have tested ceramic material which ran as high as 2,400 lb. per sq. in. As it happened, however, this material was not the highest grade high-voltage porcelain. It was not vitrified throughout, if it was vitrified at all. The fracture showed fissures, and in general its appearance was such as to lead one to think it would have a very low tensile strength.

There is a great deal of work to be done yet in connection with ceramic materials for electrical work, and undoubtedly room for great improvement. It is extremely desirable to determine the conditions which affect the mechanical strength of such material, especially the tensile strength. Some investigations I have made seem to indicate that it is possible for porcelain to have a grain, something almost of the nature of a fibre, such as we find in wood or wrought iron.

A great deal depends, with different mixes, upon the amount of moisture present when the piece is formed, and whether the piece be formed by pressing or by the plastic method. It would appear, also, that, with some porcelain mixes at least, the degree of firing has a great deal to do with the strength. In some cases it would appear that a temperature considerably below that at which the mixture will vitrify, or even begin to vitrify, will result in greater tensile strength than if the heat be carried higher.

My investigations have been confined to American porcelains. Apparently some of the European porcelains run a great deal higher in mechanical strength. In the discussion of a paper recently presented before the Institution of Electrical Engineers at Manchester, England, Professor A. Schwarz gives the results of some tests he made upon porcelain. The tensile strength ran from 3,316 lb. per sq. in., for a rectangular test piece with a section of 0.2 sq. in., down to about 2000 lb. per sq. in., for a rectangular piece of 0.6 sq. in. in section. He found a compressive strength of 10,000 lb. per sq. in., for a cylinder two in. long by two in. in diameter; 40,000 lb. per sq. in. for a

cylinder one in. in diameter, and 52,600 lb. per sq. in. for a cylinder  $\frac{7}{16}$  in. in diameter. He ascribes the lesser strength in the larger pieces to lack of heat penetration in firing, but I think it not unlikely that the apparent fibrous structure mentioned above had also a considerable amount of influence, especially if the cylinders were formed from plastic clay. It is evident that with such formation, the smaller the cylinder, the greater the proportion of its bulk that will partake of a fibrous structure.

In this matter of comparing strengths of different samples of porcelain, we, in our present ignorance, assume that all porcelain is alike. Such comparisons are about as logical as to compare tests made on high grade steel and tests made on the poorest quality of cast iron. Until this whole subject is given a more thorough study, we shall have no intelligent basis on which to compare results obtained at different times and with materials obtained from different sources.

**O. S. Lyford, Jr.:** The ideal conductor for the distribution of electric power for heavy railway operation is one that is either absolutely flexible or absolutely rigid, and parallel to the running rails. For low voltage work, which in heavy service involves the collection of large currents, the tendency is towards the rigid conductor, as characterized by the third rail. For high voltage work and consequent low current the tendency is towards absolute flexibility of structure and catenary trolley construction has been the best development thus far. Improvements in third rail construction have been in the direction of greater rigidity and improvements in catenary construction towards greater flexibility.

For intermediate voltages, it remains to be seen what construction will prevail and neither of these two, as now developed, is entirely suitable. For instance in the 1200 volt direct current system the currents are high for heavy railway operation. A locomotive such as recently adopted by one of the large railroads with motors capable of developing 4,000 h.p. in starting, the maximum current at 1200 volts would be 2800 amperes and the running current for maximum weight of train 1250 amperes. A suitable conductor for distribution of current to such locomotives must necessarily be heavy and the logical development is in the direction of rigidity of construction. This means either the perfection of a safe 1200 volt insulation for third rail or the development of a rigid overhead structure. The latter will necessarily be a very heavy and expensive construction and one open to many objections from the point of view of railway operation and maintenance. The former is possible, and is already being tried out, but if designed for usual railway clearances it will necessarily be cramped.

The two papers presented to-night relate to materials and apparatus for light structures with moderate stresses and therefore apply more particularly to constructions approaching

absolute flexibility. The discussion should be considered from that point of view.

Referring first to Mr. Kempton's paper, the tests reported verify the conclusion that porcelain used in compression is suitable for such strains as are likely to occur with a flexible and comparatively light overhead system. Referring to the question raised in the paper as to whether mechanical stresses weaken the porcelain stock electrically and therefore whether the combined mechanical and electrical test is necessary, it is the writer's belief that Mr. Kempton has arrived at the answer in the following statement:

"It was thought probable that the high stress in the section of porcelain under the load opened up slight flaws in the stock, rather than causing the sound porcelain to puncture below its unstrained puncture voltage."

It is possible that if the compression were applied to the insulator stock in such a manner as to absolutely distribute the pressure uniformly, there would be no evidence that a mechanical stress within the breaking limit weakened the insulator electrically. As a matter of fact, insulators of the style illustrated by Fig. 9 of Mr. Kempton's paper are subjected to a fairly uniform and not very heavy unit stress, this being in tension.

With the various forms of insulators for use in compression, however, the stress is not distributed uniformly, as the metal parts are necessarily elastic. For instance, in the double spool strain insulator illustrated by Fig. 29 of Mr. Smith's paper, there is necessarily some irregularity in the application of the mechanical stress to the porcelain. This difficulty also exists with the "loop" or "fish-tail" type of insulators. It was in the testing of these two types of strain insulators that we found it necessary to apply mechanical and electrical stresses simultaneously to determine the true safe limits of the insulator. It is the writers belief that after sufficient experience with a strain insulator of a given form it will not be necessary to make the combined tests on every insulator, but in this catenary work for heavy electric traction, which will usually have to be erected over a line already in operation, any reasonable expense in testing which will avoid replacement of insulators in the completed structure will ordinarily be found justifiable.

Referring to Mr. Smith's paper, the following comments are offered.

*Poles and Bridges.* There is still room for the development of a light form of pole to take the place of wood. One of the principal criticisms which maintenance-of-way officials make to the electrification with overhead trolley system is the danger to persons and property in the case of a derailment or collision which may result in overthrowing the overhead structure. It has been found that with wooden poles supporting a strong catenary structure, a derailment will result in cutting away the pole without bringing down the conductors. Heavy bridge work or heavy steel pole structures will not act as satisfactorily in such accidents.

*Messenger and Trolley Wires.* Mr. Smith refers to the use of a dynamometer in the rection of the messenger and trolley wires. Such practice was at first viewed with scorn by the superintendent who handled the Denver & Interurban work, and he has had very extensive experience in the construction of trolley work and transmission lines. Before the job was completed, however, this superintendent was enthusiastic over the results obtained, as he found time was actually saved and the structure when complete required very little readjustment and this only during construction and not after operation was begun. Since we left the job it has not been necessary to take out any slack or make material readjustments. This seems to prove also that the tension used, namely from 2000 to 5000 pounds, depending on the temperature, is entirely practicable and produces good results.

*Use of Tension Devices for Trolley Wire.* There was a question in the writer's mind as to whether the success of these devices in Europe was not due to the fact that the current collector used is very light and flexible. Such collectors are practicable in Europe where train speeds are relatively low, the variations in height of trolley are relatively small and currents collected are relatively low compared to American practice, but with the service which we are called upon to operate in this country such forms of pantagraph have thus far proved impracticable. With the American form of pantagraph shoe a pressure of at least 14 lb. seems to be necessary. Such shoes were tested out on the Pennsylvania R.R. test track and the writer watched their operation closely on the German form of catenary and compared this operation with operation on German roads previously inspected. The results, in so far as they could be noted with the brief tests on the short section of track, indicated that the American form of shoe will work as well as the European form, although this is quite contrary to the expectation of European engineers. It is the writer's belief that the success of this combination will depend on the ability to eliminate hard spots from the line. This seems possible at practically all points where high speeds are necessary.

Referring to Mr. Coomb's report that in the Pennsylvania R.R. test a form of catenary construction with one messenger and one conducting wire, the latter being supported with thin flexible hangers, gave as good results as operation on the German type of construction—this presumably relates to the action of the pantagraph shoe on the two types of conductor support, and seems reasonable to expect, as the flexibility of the simple construction is practically a great as that of the German construction provided there is sufficient distance between the messenger and the trolley wire so that the hangers are at all points long enough to be flexible. One question in relation to such a construction can be determined only by a test extending over a considerable time. This is the life of the flexible hangers. The oldest catenary trolley road in operation is that of the Stubaital-

bahn at Insbruch. On this line a simple catenary is used and the hangers are of galvanized iron wire, apparently about No. 12 in size. The writer inspected this line about two years ago and noted that many of these hangers were broken, apparently due to the vibration of the trolley wire. Such breakage will not occur with the heavier forms of trolley hangers described in Mr. Smith's paper.

Referring to the European construction mentioned by Mr. Smith, it is the writer's understanding that this construction was developed by the Allgemeine Electricitats Gasellschaft to obviate the necessity of tension devices used in the Siemens-Schuckert construction. It was believed with the use of an equalizer such as is illustrated in Fig. 16, the expansions and contractions in a catenary structure due to changes of temperature would be taken care of satisfactorily, without any other adjustment.

*Catenary Hangers.* Referring to the various forms of catenary hanger illustrated, one point which should be looked out for is that the hangers shall not damage the galvanizing of the messenger cable. This cable is an expensive item of the catenary structure and one hard to replace without delay to the traffic. It is therefore important that the life of the cable shall be as long as possible and to this end the galvanizing should remain intact. A form of hanger which has a flat loop over the messenger wire is therefore safer than a sister hook construction or any other form in which the cable may be more or less cramped. As Mr. Thurston pointed out, the design of the loop over the messenger should be such that the hanger can be moved along the messenger easily.

*Steady Strain Device.* Referring to the device illustrated in Fig. 28, of Mr Smith's paper, attention is called to the fact that the brace between the trolley wire and insulator is so short that without material change in the length of the bracket it is possible to place the steady strain insulator on either side of the main insulator and therefore always have the steady strain in tension. On other words, it is not necessary to use the steady strain as a strut which may produce a hard spot, as suggested by one of the speakers.

*Strain Insulators.* Mr. Smith makes a very good point regarding the disc type of insulator as follows:

"An excellent point about the disc type of insulator when used within its capacity is that there is a mechanical linkage of the guy cables on opposite sides of it, which prevents their falling apart if the porcelain breaks."

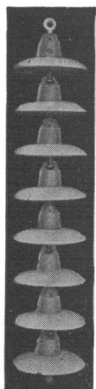
This feature should be incorporated in all strain insulator construction. It exists in the double spool strain insulator illustrated in Fig. 29 of Mr. Smith's paper. It cannot, however, be incorporated in such wood strain insulators as now employed and this is one of the principal objections to the use of wood, as either burning or breaking of the wood will throw the overhead structure out of alignment and possibly drop it.

**W. H. Kempton:** In speaking of porcelain and its quality, I do not want to give the impression that I do not have faith in it, but rather that I realize its limitations. All companies making high-voltage insulators, have developed the material to such a point that it is quite reliable; and while there is still room for improvement in porcelain insulators, and while many companies are trying to improve their quality and get more uniform results, still I think it is well to admit just how reliable porcelain is, and use that information in our designs. In that way we will avoid over-confidence, and thus get a design which will not break down in service.

Regarding Fig. 9 of the paper, I regret that I did not fully explain in the original paper that this is not a commercial insulator. It was made for the deliberate purpose of getting what Mr. Thomas points out; a pure tension stress for the purpose of a combined mechanical and electrical test.

As a matter of fact, the company with which I am connected manufactures large quantities of insulators along the line Mr. Thomas suggested: that is with the pin extended far up into the head and cemented in. We have made them with a mechanical strength of over 15,000 lb. That form was not touched on in this paper, as it is used as a suspension insulator. I did not expect to include that form of insulator in the discussion, and so avoided bringing the matter up.

Referring to the other question, regarding the protection of the insulator, I personally am convinced that the breaking of the petticoats on the insulators he described, was not due directly to electrical stresses. I have punctured many insulators and have yet to find one that broke, except under mechanical strain, or due to the heat from the arc. It is possible in the instance he described, that it was first punctured, and the heat from the following arc concentrated on that spot on the insulator, caused it to burst.



Another explanation might be added although it is rather far-fetched, and I do not think is correct; that is, that type of insulator has considerable capacity, and due to the high frequency of the lightning, it is possible there would be a marked vibration of the porcelain. But I do not think it possible to get sufficient vibration to shatter the porcelain.

The large disks of porcelain, as now manufactured, are pretty tough and I think it was the heat from the arc in the case cited, that broke the insulator. I have had them fail in a very similar manner in actual tests.

Assuming however that the insulators were broken directly by stresses due to the lightning, a remedy would be the use of suspension insulators made up of a number of units. One or more of these units might be broken without disabling the line, but I do not think it possible for all of them to be broken in that way.

The accompanying cut shows a suspension insulator made up

of eight units. Of course, the insulator may be made up of the proper number of units to suit the voltage of the line. Each of these units is ten inches in diameter and has dry flash-over voltage of 90,000 volts.

Replying to Mr. Mershon's comments, I think his statements in a measure verify my claims. As pointed out in my paper, the samples used were made without any attempt to secure extra good quality. The figures given are such that they may be used for design work with safety. As pointed out, especially prepared samples can be made with the same mixture and carefully burned and much higher results be obtained. Such samples are always made with uniform section and comparatively small. I have made tests with very much higher results, but did not give these figures for the reason that if they were used in a design, the insulator would fail to come up to the expectations of the engineer, and the manufacturer would be discredited as also would porcelain as an insulating material having mechanical strength.

Bronze is a parallel case. Government experiments show that bronze can be made with a tensile strength of 100,000 pounds per sq. in. and over, but practical foundrymen will decline to guarantee over 50,000 lb. to 60,000 lb. per sq. in.

It would be interesting to know if the dielectric strength of the samples made by Professor Schwarz was as good as the best American product. The two qualities must be worked out together. High tensile strength can be had at the expense of dielectric strength.

Mr. Mershon's criticism of my statement regarding the range of porcelain manufacture is in a measure merited. When it is considered that high voltage material must be moulded in a plastic state, dried, and then burned at a temperature that renders it pliable, it will be seen that it is difficult to make beyond a certain size and that the shape must facilitate moulding and drying the clay.

Referring to the "grain" noted by Mr. Mershon, it might be said that it is practically impossible to mould wet clay into insulator forms without its having a more or less marked fibrous structure. It might also be added that, to the best of the writer's knowledge, it is impossible to make high voltage porcelain by the "dry press" process. In the wet process, the clay is mixed with water to a plastic state when all air can be removed from the body. When the clay dries, it leaves a dense close grained body. In the "dry" process, the clay is ground up dry and made moist enough to make it retain its shape when pressed in a mould. Mechanical pressure is depended upon to make the body compact, and experience has proven that a sufficiently dense body cannot be obtained in this way for high voltage work.

There are one or two points I should like to speak of in connection with Mr. Smith's paper: one is in regard to the length of the brackets for a spacing of eight feet between the center of

the track and the center of the pole. From a rather uncomfortable experience, I found it was necessary to use a longer bracket on curves than on tangent, when the poles were placed on the outside of the curve. This is due to the rake of the pole in one direction, and the elevation of the track in the other. With these conditions it is necessary to use extra long brackets on curves, or longer ones everywhere.

Mr. Smith speaks of lining up trolley wires on the curves when pantograph trolleys are used. I think it is unwise to allow as much deviation from the center line on curves as was the practice at the beginning. There are four considerations to be borne in mind in this connection. One is the rake of the pole; two, the elevation of the outer rail; three, the speed; four, the play of the bolsters on the car.

At standstill or at slow speed on curves the pantograph trolley tends to swing toward the inside of the curve; but when running round the curve at 40 miles an hour, the momentum of the car throws it over on the bolsters toward the outside of the curve so that there is a difference of from 10 to 12 in. in the position of the trolley with respect to the wire. In one case, the line had been constructed very carefully; but in spite of that the pantograph trolley would swing out free from the trolley wire and pull down some of the line or pull the trolley from the car. It looked impossible from measurements on the line until we discovered that the construction of the car allowed it to swing over on the bolsters when going around the curve at high speed, sufficient to throw the pantograph clear of the trolley wire. The remedy in that case was to re-line-up the trolley wire and add more poles or pull-offs where necessary to reduce the offset of the trolley wire and then fix up the car to avoid such excessive swaying.

This is one of the personal experiences I have had emphasizing the care that must be exercised in the erecting of a trolley line on which pantograph trolleys are to be used.

**W. N. Smith:** The remarks of those who have joined in the discussion quite generally agree as to the fundamental principles underlying catenary construction.

As was stated by the Chairman, the overhead line still offers a great number of unsolved problems. Fortunately they are of a type capable of being attacked by the profession at large. Comparatively few electrical railway engineers have been trained as designers in electrical factories, and those who have not can hardly approach the problems of motor design at the point where the most of our alternating current railway discussions begin. Intricate theories of motor design require a mathematical ability which is not so well distributed amongst engineers generally as is the plain good sense which must underlie the planning and execution of every large undertaking in railway electrification. Problems of overhead construction, and of the equipment related thereto, are mostly mechanical, and are thus

open for solution to engineers generally on a broader and more liberal basis than is usually embraced in the commercial or manufacturing point of view—as has been indicated this evening.

Taking up the various comments in their order, it seems to me that Mr. Coombs answered Mr. Thomas's question in respect to the secondary arm or tip which has sometimes been employed at the top of the main pantagraph. This device has been used on the Simplon tunnel locomotives with sliding shoe on the tip. The Simplon locomotives travel with a maximum speed of 45 miles per hour and the contact shoes are of the sliding type. Even with the lessened inertia of this device, the shoes only last about 1700 miles.

It is true that my references to the beginnings of catenary construction applied only to its use in this country, as there has not been very much evidence that at the time of its introduction in America, our practice was influenced particularly by European methods.

Mr. Hixon's reference to wave action brings out a fundamental principle underlying successful catenary construction and operation where circumstances are favorable; that is to say, I believe that the best results will be obtained when wave action, as referred to by Mr. Hixon, is recognized and provided for. This depends very largely on the construction of hanger employed, and only experience can demonstrate which type of yielding or floating trolley hanger is really the best. The experiments mentioned by Mr. Hixon and Mr. Harte will doubtless help in determining this exceedingly important matter.

The fact that the old pole and wheel trolley operates so well with trolley wires having considerable sag, illustrates the importance of recognizing wave action, which is so much in evidence with the wheel type trolley; and this confirms my belief that the natural and desirable wave action in the trolley wire will be very much helped by the roller pantograph, and with less wear and tear than with the sliding pantograph. This point of view is based upon the probability that the heavy work of the future will be at high tensions, *i. e.*, at 11,000 volts or higher, and that the trolley pole and the narrow grooved wheel accompanying it will not be regarded as thoroughly reliable for high speed operation under steam railroad conditions, so that it will be necessary to have a transverse rolling or sliding contact which will not leave the wire under any circumstances and which the motorman or the train conductor will not be obliged to regard as an extra source of responsibility or worry. The problem becomes then one of flexible operation at high speed with a transverse contact device, and it is quite evident that the successful operation of such a combination will be met only by recognizing and providing for a vertical wave action in the trolley line.

Mr. Coombs reminds us of the fact, commonly overlooked

that the railroad track itself is not a plane surface as it is usually considered to be, and that the train itself makes a wave action in the rails as it runs over the track. This emphasizes the necessity for directing our efforts towards upward flexibility in the trolley wire, rather than to smoothness without flexibility.

With respect to the possible twisting in the compound catenary construction, illustrated in Fig. 27, as apprehended by Mr. Coombs; it would seem to me that where the wires are strung to a fairly even tension, and the hangers of the proper length, and all parts securely and tightly drawn up, there would not be any tendency to roll when the line is properly adjusted. If one of the wires is much tighter than the other there will, of course, be a tendency for the structure to get out of position.

I agree with Mr. Thurston that it is very desirable to have the connection at the top of the spacing rod flexible, so as to allow it to move with reference to the messenger wire. This is an instance of the value of practical experience—in showing the value of flexibility, which engineers were chary of a few years ago.

Mr. Harte emphasized the interesting fact that successful operation depends on uniformity of resistance at the contact surface, *i.e.*, hard spots should be kept out of a yielding line or soft spots out of a hard line, or, in other words, the line should be either uniformly hard or uniformly yielding. The successful operation of the Denver & Interurban catenary line has been due to the fact that it was uniformly hard and smooth, and the reason why it was built in that manner was, in the first place, because it was necessary to use the sliding pantograph bow, the wheel trolley being regarded as impracticable; secondly, we had to make use of such types of hangers as were commercially available at the time, there being no flexible type hangers of known reliability then manufactured; consequently it was impossible to construct a line which we could be sure would be uniformly flexible, and we were therefore obliged to adopt the method of making the line uniformly hard and smooth, which was done in the manner indicated in the paper, and which has proved to be successful as a working proposition. Having no means for making the line flexible, we did the next best thing; and while I will readily admit that it would in some respects have been an easier line to build if it had not been necessary to draw it so tight, two years of operation and maintenance have developed no defects, and apparently it is as satisfactory to operate as though it were of the flexible type.

The experimental lines constructed with flexible hangers mentioned by Mr. Hixon and Mr. Harte will doubtless have considerable effect in determining the development of catenary details, but it now appears that both the Schenectady and Connecticut lines are operating with wheel trolleys and not with sliding bows. It seems to me that the contact-making conditions which must be ultimately fulfilled by equipment

for heavy traction are not being met in these installations, and to that extent they will be somewhat inconclusive. If they should be tried out with pantagraph trolleys of the sliding or roller type, then there would be something definite upon which to base conclusions for the heavy and high speed work of the future.

The question of clearance referred to by Mr. Kempton, is, of course, one that pertains to conditions on each particular job; 8 feet was mentioned as a minimum which was actually used in a large installation without any bad results. I believe, however, that  $8\frac{1}{2}$  feet is better, as used on the Denver & Inter-urban line.

The inclination of the trolley brackets on curves was varied from the horizontal; if car leaned away from the pole, the bracket is inclined downwards; if toward the pole, the bracket is inclined upwards, in order to prevent the horizontal pantograph bar from fouling the bracket arm.

The roller type of trolley contact has been in use in Europe for some years; the Valtellina installation in Italy being perhaps the best known instance of its application there. I referred to its use on the Pacific coast as the first and only application of its use in this country. Since writing the paper I have ascertained through the *Electric Journal* that on the Valtellina line, where the overhead construction is not very tight (and not of the catenary type) the rollers have an average life of 15,500 miles and frequently carry more than 200 amperes per roller, and that in the opinion of Mr. Von Kando of the Italian Westinghouse Co. the excellent life of the contact roller is due partly to the difference between rolling and sliding friction, and partly to the fact that each element of the roller is heated by the passing current only at the instant of contact, and does not remain in contact long enough to get melted; while with the sliding contact the wear is excessive when the current is more than 50 amperes.

It seems to be agreed that the vertical flexible working conductor is very desirable, and the best reports of smooth operation with it emanate from installations where the rolling and not the sliding contact is used.

It is my belief that trolley pole and wheel are not suitable for heavy railroad operation at high tensions and speeds, and that the horizontal transverse form of contact device is indispensable under such conditions; and I suggest that the next step forward should be in the development of the roller type of contact against the yielding or floating trolley wire, in which the elements of wire tension, contact pressure, and pantograph inertia will be compromised to produce the desired effect.

It has been stated by men who have had good opportunities for actual observation, that when speeds of 45 miles per hour or so are exceeded, the conditions to be met by an overhead contact device for heavy currents are so difficult as to be beyond the

field of experience at lower speeds. Granting this to be true, there is all the more reason for developing practical mechanical devices for making contact. Only experiment can decide the question positively, and it remains to be seen whether the devices above suggested can be adapted to high speed, or whether recourse must be had to some combination yet to be invented.

**Edwin B. Katte** (by letter): The following is a description of porcelain strain insulators used upon a recently constructed 11,000-volt aerial transmission line and a 650-volt direct current distribution system.

*Specifications.* The 11,000-volt strain insulators shall be of two piece construction; the 650-volt strain insulators shall be a single piece of porcelain. Porcelain surfaces shall be thoroughly glazed a uniform brown color, shall be free from pits, cracks or other imperfections and the material sound and homogeneous throughout. All insulators shall conform to the dimensions

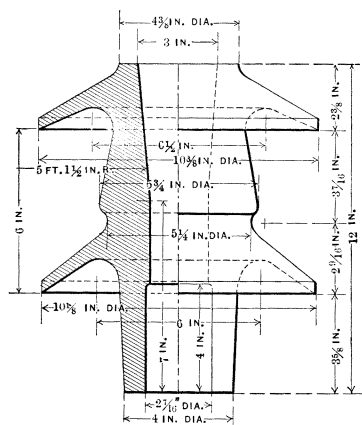
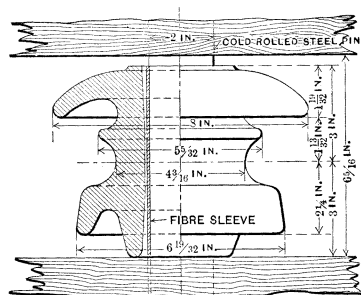


FIG. 1.—High-tension insulator



NOTE:—THIS PIN AND INSULATOR MAY BE USED FOR DEAD ENDING 150 FT. 1 MILLION C.M. SPAN.

FIG. 2.— Low-tension insulator

given on the attached illustration, Fig. 1 and Fig. 2, within  $3/32$  in. except those given for pin holes which shall conform to the drawing to within  $1/16$  in.

*Tests.* The contractor shall supply for test free of cost 2 per cent of the insulators from each furnace charge. These shall be broken and on the exposed surface shall be placed drops of red ink which shall not spread or show signs of absorption. The exposed surface shall be free from cracks, checks, blow-holes, etc., and shall show a close and uniform grain.

*A. High Tension Strain Insulators.* Each 11,000-volt strain insulator selected by the inspector shall be mounted on a two-in. metal pin, shall be subjected to a potential of 80,000 volts applied between the pin and the wire groove for one minute without showing signs of breakdown, leakage or excessive brush discharges. When mounted in a vertical position on a 2-in. metal pin and

subjected to a precipitation of  $\frac{3}{4}$  in. of clear water per minute with current applied between pin and wire groove the insulators shall not break down or arc over at less than 50,000 volts. Each insulator when mounted upon a steel bar in a manner to be approved by the engineer shall safely withstand a continuous load perpendicular to the pin of 9,000 lb. applied by means of a No. 4/0 seven-strand, hard-drawn copper cable.

B. *Low Tension Strain Insulators.* Each 650-volt strain insulator selected by the inspector shall be mounted on a 2-inch metal pin, shall be subjected to a potential of 30,000 volts applied between the pin and the wire groove for one minute without showing indications of conductivity, breakdown or surface leakage. When mounted in a vertical position on a 2-inch metal pin and subjected to a precipitation of  $\frac{3}{4}$  of an inch of clear water per minute with current applied between pin and wire groove the insulator shall not break down or arc over at less than 16,000 volts. Each insulator when mounted upon a steel bar in a manner to be approved by the engineer shall safely withstand a continuous load perpendicular to the pin of 10,000 lb. applied by means of a 1,000,000 circular mill, 91-strand, hard-drawn copper cable. Each insulator shall withstand, momentarily, without sign of fracture, 15,000 lb. applied in the manner specified.

#### SUMMARY OF TESTS

Type of insulator	Electrical requirements
11,000-volt strain.....	Dry, 80,000 volts for one minute. Wet, 50,000 volts without arcing.
650-volt strain.....	Dry, 30,000 volts for one minute. Wet, 16,000 volts without arcing.
	Mechanical requirements
11,000-volt strain.....	Continuous load of 9,000 lb.
650-volt strain.....	Continuous load of 10,000 lb.
650-volt strain.....	Momentarily load of 15,000 lb.

*Inspection Results.* Competitive bids were invited for high and low tension strain insulators and the contract finally awarded to an insulator manufacturer of high standing. Insulators were offered for inspection and acceptance with the following results:

Type of insulator	Total No. delivered	Number accepted	Per cent rejected
11,000-volt strain.....	156	129	17.3
650-volt strain.....	172	163	5.2

*Mechanical Tests.* From a large number of tests to determine the mechanical strength of the insulators the following have been selected as typical:

#### 11,000 VOLT STRAIN INSULATORS

No. of test	Pounds pressure	Time pressure applied	Remarks
13	11,390	5 mins.	O. K.
13	13,400	3 mins.	Cracks developed.
13	13,735	Instantly	Failure.
14	8040	10 mins.	O. K.
14	10 720	2 mins.	Cracks developed.
14	11,055	Instantly.	Failure.

## 650 VOLT STRAIN INSULATORS

11	6,700	5 mins.	O. K.
11	10,050	3 mins.	O. K.
11	10,385	Instantly	Failure.
12	8,710	3 mins.	O. K.
12	12,060	2 mins.	O. K.
12	13,400	Instantly.	Failure.

*Results in Service.* The insulators described above have been in continuous service for about three years with the following results.

Type of insulator	No. in- stalled	Mech. failures	Elec. failures	Broken by violence	Per cent Failure from all causes
High tension strain.....	101	5	0	0	4.9
Low tension strain.....	86	8	0	0	9.4

*Conclusions.* It must be concluded from the above that the per cent of mechanical failures has been high considering the care with which the original shipments were inspected and tested. For the relatively low voltages there is no difficulty in securing the requisite electrical strength, but further combined efforts of engineers and manufacturers are necessary to secure greater mechanical strength in porcelain strain insulators for heavy service.