Aug. 17, 1943. F. G. FOWLE ET AL 2,327,256

CARBON-STEEL ALTERNATING-CURRENT CONDUCTOR

Original Filed Aug. 2, 1941

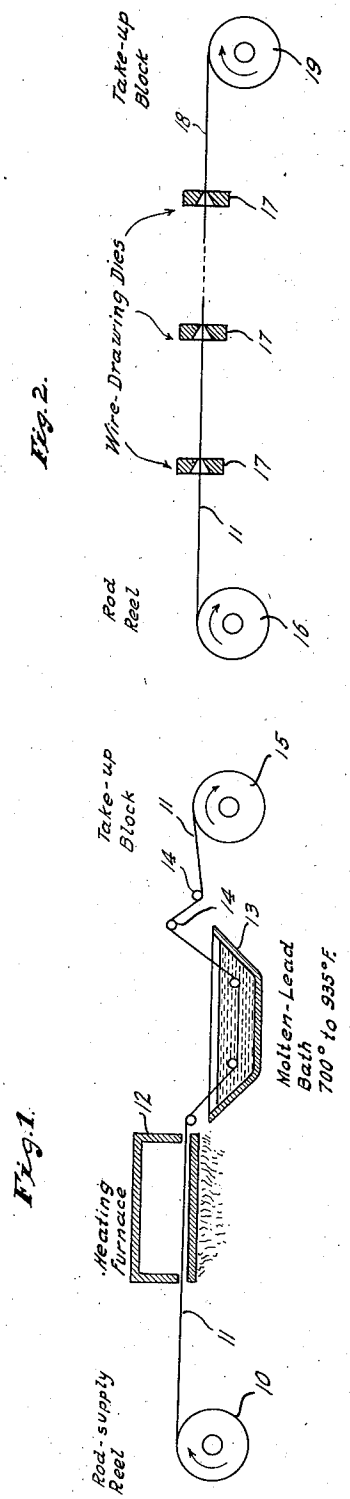

Fig. 1.

Fig. 2.

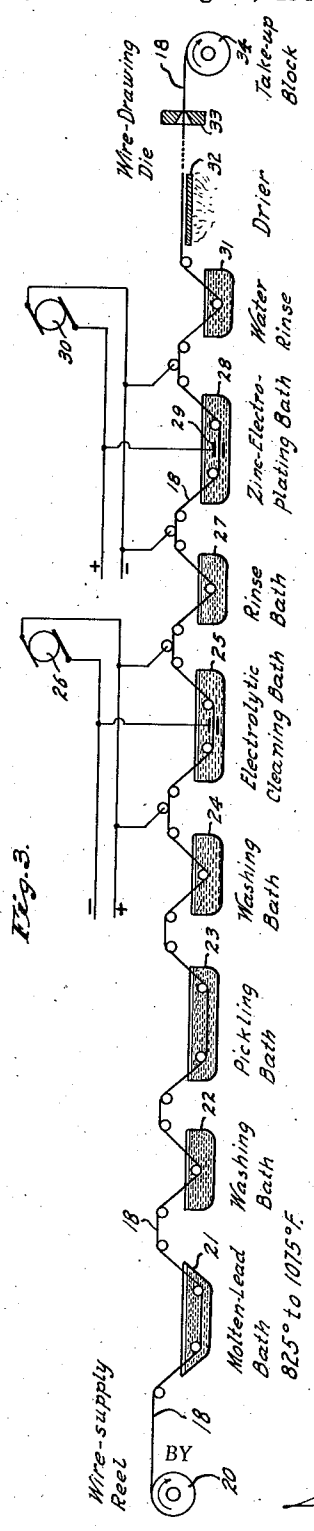

Fig. 3.

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CARBON-STEEL ALTERNATING-CURRENT CONDUCTOR

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Original application August 2, 1941, Serial No. 405,232. Divided and this application May 16, 1942, Serial No. 443,312

10 Claims. (Cl. 174—134)

Our invention relates to high-strength carbon-steel alternating-current conductors, having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance.

The present invention, in certain aspects, is an improvement over certain things that are disclosed in the following patents, granted to one or both of us:

Crapo, No. 1,942,411, granted January 9, 1934,
Crapo, No. 2,019,445, granted October 29, 1935,
Fowle and Crapo, No. 2,019,447, granted October 29, 1935,
Crapo, No. 2,118,008, granted May 17, 1938,
Crapo, No. 2,118,758, granted May 24, 1938.

The present application is a division of our co-pending application Serial No. 405,232, filed August 2, 1941, and is filed in compliance with a requirement for division in that co-pending application. In addition, like that co-pending application, it is a continuation in part of our other co-pending applications Serial Nos. 207,351 and 207,352, both filed May 11, 1938, and of our co-pending application Serial No. 256,112, filed February 13, 1939, which last application is now Patent No. 2,283,868, granted May 19, 1942.

It is the object of our present invention to obtain a carbon-steel conductor having characteristics—mechanical, magnetic, and electrical—which make it exceptionally suitable for alternating-current transmission lines, especially overhead lines. The term "alternating current" is used to include pulsating current.

The carbon-steel conductor contemplated by the present application, intended primarily for use in an overhead alternating-current transmission line, is of hypoeutectoid steel which contains over 0.20% and desirably at least 0.25% of carbon and for best results not over 0.65% of carbon, not in excess of 0.30% of manganese, desirably not in excess of 0.10% of silicon, and desirably not in excess of 0.05% of phosphorus. This matter of composition or analysis is an essential part of our invention; but it is only one part of our invention, for an equally important part, if not a more important part, is the treatment to which the wire of this composition or analysis is subjected in its fabrication.

We have discovered the surprising fact that if in the fabrication of a wire of this composition or analysis we subject the rod to a special heat-treating operation by heating it to a temperature above the Ac_3 temperature and quenching it from above that Ac_3 temperature in a bath of molten lead (or equivalent molten metal) maintained within a certain range of temperature, hereinafter discussed more fully, and thereafter subject that specially heat-treated rod to wire drawing, even if thereafter we subject the drawn wire (as we may and preferably do) to a process tempering within a certain range of temperature, we get an ultimate wire which not only has a high tensile strength and a good elongation but has a lower alternating-current resistivity than has any prior ferrous wire of which we know.

In addition to this electrical effect, which is interrelated with a lowered magnetic permeability and hence with a lowered skin effect and a lowered reactance, we get certain highly advantageous mechanical effects, of great importance in a conductor for an overhead electric transmission line—such as high tensile strength and good elongation (above referred to), and toughness, resistance to shock, and high fatigue endurance. By a combination of these mechanical properties with the above electrical and magnetic properties, we get an optimum set of characteristics that is most surprising.

The molten lead (or equivalent metal) used for the special heat-treating bath is maintatined between 700° and 935° F. But for best results, the temperature of the molten-lead bath is not only within that range, but is in a certain part of that range dependent upon and increasing with the carbon content of the wire. A rough formula for the optimum temperature of the molten-lead bath is the sum of 675° F. and a number of degrees equal to 375 times the percentage of carbon in the wire, with a maximum temperature of 935° F. For best results, the bath temperature should be within 50 degrees of the optimum temperature so determined.

Another surprising fact is that the process-tempering which we preferably do after the wire-drawing of the specially heat-treated wire of the specified composition or analysis not only markedly increases the ductility and elongation while only slightly lessening the tensile strength, but in addition does not have the usual effect of increasing the magnetic permeability (and therefore increasing the skin-effect resistance ratio and hence the A.-C. resistivity), and may have a slight directly reverse effect of lowering the permeability and the skin-effect resistance ratio and the A.-C. resistivity.

This peculiar combination of effects adds up to a set of properties in the conductor which make it especially advantageous for use in an overhead alternating-current transmission line—in-

deed the best ferrous conductor for such use ever known.

The process of fabricating our conductor involves the following steps:

We start with a hot-rolled hypo-eutectoid carbon-steel rod having the desired composition or analysis—carbon over 0.20% and desirably at least 0.25% but below the eutectoid point of 0.85% and for best results below 0.65%, manganese not in excess of 0.30% and desirably as low as possible, silicon desirably not in excess of 0.10% and as low as possible, phosphorus desirably not in excess of 0.05%, sulfur low although not necessarily absent, and some copper present if it is desired to have a copper-bearing steel. By the term rod, as here used, we include the larger wires which may have been produced from the original rod by one or more passes through wire-drawing dies but which are still to be drawn to make smaller wires.

1. We first heat-treat this rod in our special way, which has never been used in producing wires of this composition or analysis, and which with such wires is found to have the especially beneficial effects above referred to, on electrical, magnetic, and mechanical properties. This special heat-treating involves heating the rod of the specified composition or analysis to a temperature above the upper critical temperature (the Ac_3 temperature), and then quenching through the critical range in a molten-lead bath having a temperature between 700° and 935° F.—being higher (other things being equal) for increased carbon content. The optimum temperature of this bath is determined by the formula given above.

2. After the rod has been thus specially heat-treated, it is then subjected to suitable pickling and/or other preparations for wire drawing, and is then drawn to a wire of the desired size or substantially the desired size. This drawing increases the tensile strength, and usually produces a rather high tensile strength, perhaps of the order of 150,000 to 200,000 pounds per square inch; but this high tensile strength is accompanied by a low elongation, of the order of about 1% to 2% (measured in 10-inch lengths). The ductility of the wire in this condition is undesirably low for a conductor of an overhead electric transmission line. The wire-drawing not only increases the tensile strength, but, with the special-composition wire that has had the aforesaid special heat-treatment, the drawing also lowers the magnetic permeability, and so lowers the skin effect and the A.-C. resistivity.

3. When the desired size has been obtained, the wire is preferably process-tempered. In that process-tempering, which is a partial annealing, we heat the wire to a selected temperature, which is well below the lower critical temperature (the Ac_1 temperature). That selected temperature may vary somewhat, as with the composition of the wire, being higher (other things being equal) for increased carbon content. It may also vary according to the tensile strength and elongation desired, being higher for greater elongation and less tensile strength. This process-tempering or partial annealing increases the ductility and elongation markedly, often several fold; and while it also decreases the tensile strength, it does so to a much smaller degree. It partially but only partially eliminates the effects of the cold working; and so allows effects of the cold working in part to persist in the final conductor. The process-tempering temperature is between 825° and 1075° F. It may be obtained in various ways, as by passing the wire through a muffle furnace, or through a molten-material bath (such as molten lead or molten salt), maintained at that temperature. After the wire has reached this selected temperature, it is then allowed to cool, as by being passed through ordinary air. In some cases this process-tempering may be omitted.

4. The wire may be used in this condition, or it may be suitably coated or covered with any desirable metal, such for instance as zinc, lead, copper, or aluminum, and/or with a non-metal of any suitable character. If zinc, the most common coating metal, is used for the coating, it may be applied by either hot-dipping or electrodeposition. To put on any coating, the wire must be suitably prepared, for instance by passing it through a pickling bath, one or more water-washing baths, and an electrolytic cleaning bath. If the wire is coated, it may be further slightly drawn following the application of the coating.

Whether with or without a coating, our carbon-steel wire, of the specified composition or analysis and produced by the specified treatment, is found to be particularly effective as a conductor in an overhead electric transmission line, especially for alternating currents. The special heat treatment makes the wire tough and more resistant to shock; and produces a type of sorbitic structure, which is probably the source of the increased toughness and resistance to shock. That increased toughness permits more wire-drawing; and the cold-working produced by the wire-drawing raises the tensile strength to high values. The subsequent process-tempering, under the conditions specified, lowers the tensile strength somewhat, but if done carefully it raises the ductility and the elongation in greater proportion than it lowers the tensile strength; for it may double or treble or sometimes even quadruple the elongation, while lowering the tensile strength by only a relatively small amount. The final conductor thus has persisting in its grain structure electrical, magnetic, and mechanical effects produced (*a*) by quenching through the critical range in a bath of molten material having a temperature between 700° and 935° F., (*b*) by cold-working, and (*c*) by subsequent partial-annealing.

The effect of our special heat-treatment on the magnetic permeability of a wire of this composition or analysis, and so on the skin effect and on the A.-C. resistivity of such wire, is unexpectedly markedly greater, and to us unexplainably greater,

a. Than if a wire of the same composition or analysis is subjected to the so-called "air patenting" (or "Old Process patenting"), in which air is used as the cooling medium,

b. Than if a wire of the same composition or analysis is subjected to "patenting" in a liquid medium (whether metal or not) maintained at a lower or a higher temperature than the one we here maintain, and

c. Than if a wire of a different composition (in which the carbon content and the manganese content are outside the ranges which we have indicated) is subjected to "patenting" of any character.

This marked lowering of magnetic permeability of our special-composition wire, and so of its skin effect and its A.-C. resistivity, is augmented by the cold-working of the wire—which individual result is not in itself unexpected, but which when com-

bined with the special heat-treatment of our special-composition wire produces in such wire a lower A.-C. resistivity than has ever been known in a ferrous wire.

Further, when we process-temper this specially heat-treated and drawn wire of this special composition or analysis, at the temperature ranges which we have indicated, we do not get the raising of magnetic permeability, and so of skin effect and of A.-C. resistivity, which would normally be expected to result from such process-tempering—and which does result from such process-tempering even in a wire of the same analysis if our special heat-treating procedure is omitted. Instead, our process-tempering leaves the permeability and the skin effect and the A.-C. resistivity no greater than they were, and often reduces them. This effect which we obtain from our process-tempering is dependent both on the composition or analysis of the wire and on the heat-treating of the wire in our special way; for otherwise the process-tempering raises the magnetic permeability and the skin effect and the A.-C. resistivity.

Thus the three steps of special heat-treatment, wire-drawing, and process-tempering, when applied to wires of our specified composition or analysis, co-operate in a new and useful way, and one which is distinctly unexpected and which we can not at present explain.

As a result of this co-operation, our wire is especially suitable for the conducting of alternating currents both of power frequency (usually 50 or 60 cycles per second) and audio frequency (between about 100 and several thousand cycles per second). Also, its mechanical properties make it especially suitable for overhead electric transmission lines, both power lines and communication lines; for the high tensile strength permits the wire to be supported overhead in longer spans than is possible in wires of less tensile strength, and its good elongation, its toughness, its resistance to shock, and its high fatigue endurance, co-operate with that high tensile strength to this end.

The accompanying drawing illustrates an apparatus in which the process for making our high-strength carbon-steel alternating-current conductor is performed. In such drawing: Fig. 1 is a diagrammatic view of an apparatus for performing our special heat-treatment; Fig. 2 is a diagrammatic view of an apparatus for performing the wire-drawing step or steps; and Fig. 3 is a diagrammatic view of an apparatus for performing our special process-tempering step and for electro-galvanizing, with some intervening steps.

The hot-rolled rod of the specified composition or analysis, outlined above, is obtained from a rolling mill. This requires special heats of steel to get that desired composition or analysis—selected between 0.20% and 0.85% carbon but desirably above 0.25% carbon and for best results below 0.65% carbon, and between zero and 0.30% manganese, and desirably between zero and 0.10% silicon and between zero and 0.05% phosphorus, suitably little sulfur, and if desired some copper—for steel mills seldom if ever produce such a steel. Indeed, so far as we known, no steel mill has ever produced such steel except in accordance with our instructions.

A coil of rod, after some preliminary drawing if desired, is put on a supply reel **10** (Fig. 1), from which the rod **11** passes through a heating furnace **12**, suitably heated so that the rod is raised to a temperature above the Ac_3 temperature. From the heating furnace, the rod **11** is passed directly into a molten-lead bath **13** in which the proper temperature is maintained as explained above—in any case between 700° and 935° F. From the molten-lead bath **13**, the rod **11**, after passing if desired over reverse rollers **14** to remove scale, passes to a take-up block **15**.

The specially heat-treated rod **11** is then removed from the take-up block **15**, suitably cleaned and otherwise prepared for drawing, and put on a supply reel **16** (Fig. 2); from which it is fed through wire-drawing dies **17**, in which the rod **11** is drawn to a wire **18**. The wire is pulled through the dies **17** by a take-up block **19**, on which the drawn wire is coiled. If there are a large number of wire-drawing dies **17**, as there may be when the wire **18** is drawn to small diameter from a large rod, it may be desirable to do the wire-drawing in several steps; and even to repeat the special heat-treating at an intermediate stage in the drawing of the wire, with the lead-quenching temperature as set forth above, as in the apparatus shown in Fig. 1.

When the wire **18** has been drawn to the proper size, it is removed from the take-up block **19** and put on a wire-supply reel **20** (Fig. 3); from which it is fed to obtain the special process-tempering, and then if desired a suitable coating, such for instance as zinc coating. To this end, the wire **18** passes from the wire-supply reel **20** into a molten-lead or molten-salt bath **21**, in which the lead or salt is maintained at a temperature between 825° and 1075° F. For higher carbon contents the temperature of the molten lead or molten salt is desirably in the upper part of this range, while for lower carbon contents it is desirably in the lower part thereof. The molten lead or molten salt in the bath **21** is a temperature-raising liquid, as distinguished from the temperature-lowering liquid of the molten lead of the bath **13**. After passing through the molten-material bath **21**, the wire **18** is cooled in any suitable manner, as by being passed through the air.

The wire **18** before it is passed into the molten-material bath **21** has a very high tensile strength, but its elongation and its ductility are too low. In the molten-material bath **21** there is a tempering action that is very carefully controlled, to increase the ductility and the elongation to desired values without lowering the tensile strength too greatly. By careful selection of the temperatures within the range indicated, it is possible to keep the tensile strength above 120,000 pounds per square inch, and in most cases above 130,000 pounds per square inch, and yet to increase the elongation to a final value of the order of 4% to 8%, in ten-inch lengths. With such tensile-strength and elongation values, the wire is an eminently suitable conductor for overhead electric transmission lines.

In addition, the wire is an eminently suitable alternating-current conductor, because of its low A.-C. resistivity, explained above.

If desired, and as the drawing shows, after the wire **18** has left the bath **21** it may then be passed through various baths in preparation for coating—here shown as zinc coating by electro-galvanizing. In that case, such preparatory baths may include a washing bath **22**, containing washing water, a pickling bath **23**, another washing bath **24** also containing washing water, an electrolytic cleaning bath **25** in which through suitable electrical connections a flow of current from a generator **26** is produced between the wire **18**

and a suitable electrolyte in the bath to cause a cleaning of the wire in known manner, and a rinsing bath 27 for a final rinsing just prior to electro-plating with zinc. From the rinsing bath 27 the wire 18 passes into an electro-galvanizing bath 28, containing a suitable electrolyte for electro-depositing zinc on the surface of the wire, and provided with suitable anodes 29 for the electrolyte used. Current from a generator 30 is supplied, through suitable electrical connections, to the wire 18 and to the anodes 29, to produce the desired electro-plating of the wire with zinc.

On leaving the electro-galvanizing bath 28, the wire passes through a water-rinsing bath 31, and then desirably over a drier 32. If desired, it may then pass through an additional wire-drawing die or dies 33, although this may be omitted. Whether or not there is any additional wire-drawing die 33, the wire 18 finally passes to a take-up block 34, which furnishes the power for pulling the wire through all the apparatus shown in Fig. 3.

The unexpected results obtained with our conductors are apparent by contrasting the properties of our conductors with those of conductors of the earlier patents referred to above, and by the following table comparing certain of our conductors with certain other conductors of identical composition but differently treated. The five samples of wire of the following table were all drawn to No. 12 BWG size from No. 5 hot-rolled rod, all were bare (uncoated) wires, and all had the following composition:

	Percent
C	0.40
Mn	0.22
Si	0.01
P	0.015
S	0.025

The respective samples of the table were subjected to the following treatments:

A. No heat-treatment of rod—no process-tempering of wire.
B. No heat-treatment of rod—wire process-tempered (850° F.).
C. Our special heat-treatment of rod—no process-tempering of wire.
D. Our special heat-treatment of rod—wire process-tempered (850° F.).
E. Our special heat-treatment of rod—wire process-tempered (1020° F.).

Properties of these sample conductors are shown by the following table:

Sample	Tensile strength, pounds per square inch	Elongation, per cent, in 10-inch lengths	A.-C. resistance, ohms per 1,000 ft. 5 milliamperes at 1,000 cycles. Measured at 80° F.	Skin-effect resistance ratio, 5 milliamperes at 1,000 cycles	Apparent permeability, 5 milliamperes at 1,000 cycles
		Per cent			
A	128,000	2.0	8.58	1.297	64.0
B	127,000	3.5	8.93	1.359	68.0
C	178,000	2.5	7.89	1.189	52.2
D	170,000	7.0	7.81	1.183	52.3
E	131,000	8.1	7.73	1.179	51.2

These figures vary somewhat with variations in composition and in treatment within the ranges which we have specified. For instance, if the initial rod with which we start has a carbon content of about 0.30%–0.35%, an iron content of about 99.55%, and a maximum of about 0.15% for the sum of the manganese, silicon, phosphorus, and sulfur, a conductor may be produced by our process with a tensile strength of about 140,000 pounds per square inch, an elongation of about 8%, and an effective A.-C. resistance, measured at 80° F. in bare (uncoated) wire of No. 12 BWG size, as low as 7.2–7.3 ohms per thousand feet to currents of 5 milliamperes at 1000 cycles per second. In general, bare wires of No. 12 BWG size produced by our process have an effective A.-C. resistance to currents of 5 milliamperes at 1000 cycles per second of the order of 7.2 to 8.3 ohms per thousand feet, measured at 80° F.

We claim as our invention:

1. A carbon-steel alternating-current conductor which is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which has a tensile strength above 120,000 pounds per square inch, has an elongation of the order of 4% to 8%, and when in bare wire of No. 12 BWG size has an effective A.-C. resistance to currents of 5 milliamperes at 1000 cycles per second of the order of 7.2 to 8.3 ohms per thousand feet, measured at 80° F.

2. A carbon-steel alternating-current conductor which is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which when in bare wire of No. 12 BWG size has an effective A.-C. resistance to currents of 5 milliamperes at 1000 cycles per second of the order of 7.2 to 8.3 ohms per thousand feet, measured at 80° F.

3. A carbon-steel alternating-current conductor which is made of hypoeutectoid steel containing at least 0.25% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which when in bare wire of No. 12 BWG size has an effective A.-C. resistance to currents of 5 milliamperes at 1000 cycles per second of the order of 7.2 to 8.3 ohms per thousand feet, measured at 80° F.

4. A carbon-steel alternating-current conductor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which conductor is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which has persisting in its grain structure electrical, magnetic, and mechanical effects produced (*a*) by quenching through the critical range in a bath of molten material having a temperature between 700° and 935° F., (*b*) by cold-working, and (*c*) by subsequent partial-annealing.

5. A carbon-steel alternating-current conductor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which conductor is a wire of hypoeutectoid steel which has a tensile strength above 120,000 pounds per square inch, has an elongation of the order of 4% to 8%, and when in bare wire of No. 12 BWG size has an effective A.-C. resistance to currents of 5 milliamperes at 1000 cycles per second of the order of 7.2 to 8.3 ohms per thousand feet, measured at 80° F.

6. A carbon-steel alternating-current conduc-

tor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which when in bare wire of No. 12 BWG size has an effective A.-C. resistance to currents of 5 milliamperes at 100 cycles per second of the order of 7.2 to 8.3 ohms per thousand feet, measured at 80° F.

7. A carbon-steel alternating-current conductor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which conductor is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which has a sorbitic structure, and which has been subjected to cold-working and to subsequent partial annealing by which the effects of the cold-working have been partially but only partially eliminated so that effects of that cold-working in part persist, and which has a tensile strength above 120,000 pounds per square inch and an elongation of the order of 4% to 8%.

8. A carbon-steel alternating-current conductor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which conductor is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which has a sorbitic structure, and which has been subjected to cold-working, and which has a tensile strength above 120,000 pounds per square inch.

9. A carbon-steel alternating-current conductor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which conductor is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which has persisting in its grain structure electrical, magnetic, and mechanical effects produced by quenching through the critical range in a bath of molten material having a temperature between 700° and 935° F., and which has been subjected to cold-working and to subsequent partial annealing by which the effects of the cold-working have been partially but only partially eliminated so that effects of that cold-working in part persists; and which has a tensile strength above 120,000 pounds per square inch.

10. A carbon-steel alternating-current conductor having lowered magnetic permeability and lowered skin effect, resulting in lowered effective alternating-current resistance and reactance, which conductor is made of hypoeutectoid steel containing at least 0.20% of carbon, not in excess of 0.30% of manganese, not in excess of 0.10% of silicon, and not in excess of 0.05% of phosphorus, and which has a sorbitic structure, and which has been subjected to cold-working and to subsequent partial annealing by which the effects of the cold-working have been partially but only partially eliminated so that effects of that cold-working in part persist, and which when in bare wire of No. 12 BWG size has an effective A.-C. resistance to currents of 5 milliamperes at 1000 cycles per second of the order of 7.2 to 8.3 ohms per 1000 feet, measured at 80° F.

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FREDERICK M. CRAPO.

CERTIFICATE OF CORRECTION.

Patent No. 2,327,256. August 17, 1943.

FRANK F. FOWLE, ET AL.

It is hereby certified that error appears in the above numbered patent requiring correction as follows: In the heading to the drawing, line 1, for "F. G. FOWLE ET AL" read --F. F. FOWLE ET AL--; page 4, first column, line 4, for "zine" read --zinc--; page 5, second column, line 16, claim 9, for "persists" read --persist--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 7th day of December, A. D. 1943.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)

CERTIFICATE OF CORRECTION.

Patent No. 2,327,256. August 17, 1943.

FRANK F. FOWLE, ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 5, first column, line 6, claim 6, for "100 cycles" read --1000 cycles--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 18th day of December, A. D. 1945.

Leslie Frazer

(Seal) First Assistant Commissioner of Patents.