July 24, 1951 R. L. HARVEY 2,561,495

HIGH-LOSS MAGNETIC CORE FOR HIGH-FREQUENCY COILS

Filed Aug. 26, 1947

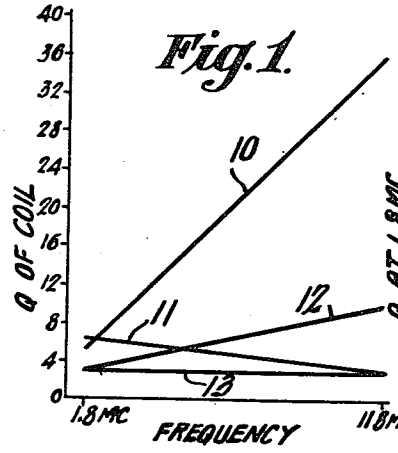


Fig. 1.

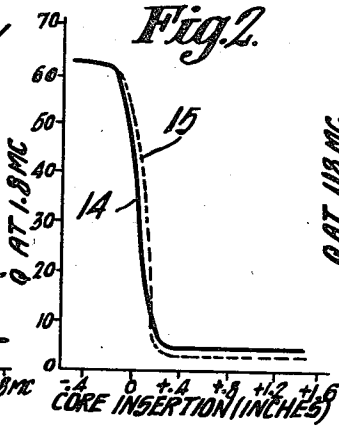


Fig. 2.

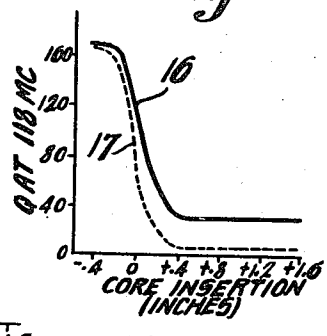


Fig. 3.

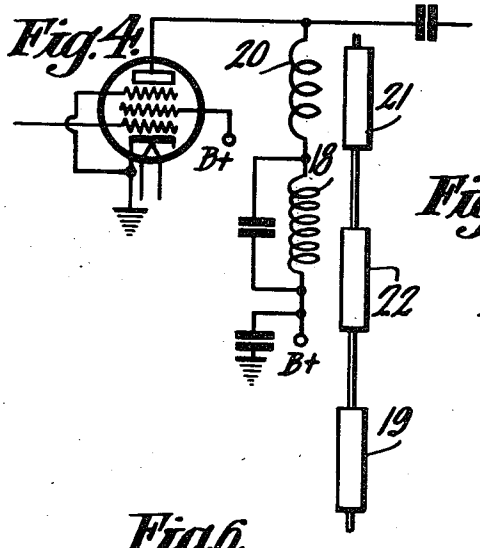


Fig. 4.

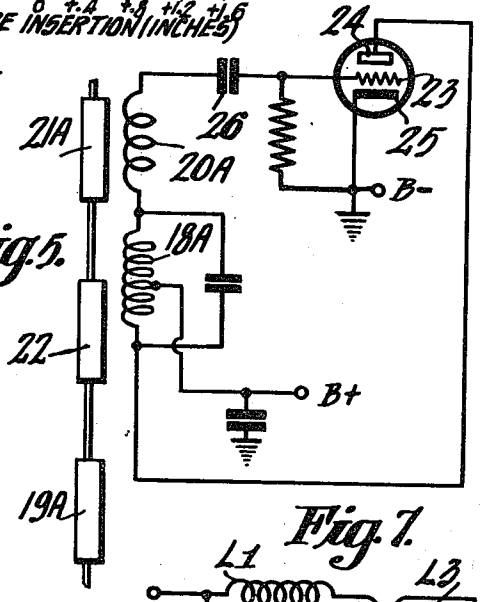


Fig. 5.

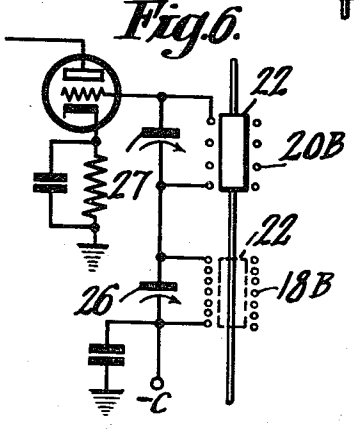


Fig. 6.

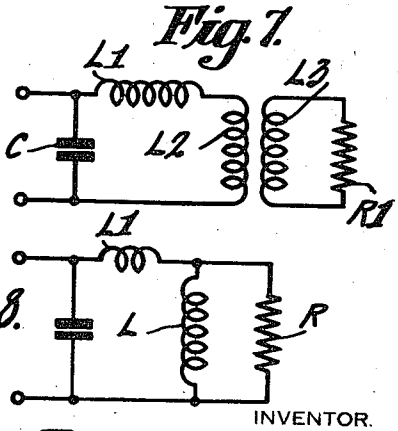


Fig. 7.

Fig. 8.

INVENTOR.

Robert L. Harvey

BY J. G. Norton

ATTORNEY

Patented July 24, 1951

2,561,495

UNITED STATES PATENT OFFICE

2,561,495

HIGH-LOSS MAGNETIC CORE FOR HIGH-FREQUENCY COILS

Robert L. Harvey, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application August 26, 1947, Serial No. 770,729

2 Claims. (Cl. 171—242)

1

This invention relates to cores for radio-frequency coils and particularly to high-loss cores for effecting switchless band-shifting in multi-band circuits.

It is an object of the invention to provide a high-loss core having such ratio of resistance to permeability that its inclusion in the magnetic field of a high-frequency coil so reduces the Q of the coil that its resonance effect is inappreciable.

It is a further object of the invention so to predetermine the resistance and permeability of the core for a selected frequency band that the Q of the associated coil remains substantially constant over that band or increases or decreases at desired rate with increase of frequency.

In accordance with the invention, a core is made by pressing a mass of finely divided metal, preferably iron or equivalent magnetic material, into the desired shape and then subjecting the core to a sintering temperature for a predetermined time. By selection of the material and its fineness, of the pre-sintering pressure, and of the sintering period and temperature, any of many core-loss/frequency characteristics may be predetermined and reproduced.

The invention further resides in the high-loss cores and in the methods of making them hereinafter described and claimed.

For a more detailed understanding of the invention, reference is made to the accompanying drawings, in which:

Figs. 1 to 3 disclose characteristic curves referred to in discussion of the invention;

Figs. 4 to 6 are partial schematic diagrams of multi-band circuits utilizing the invention; and

Figs. 7 and 8 are explanatory figures referred to in discussion of damping cores and their circuit equivalents.

Particularly in multi-band circuits such as disclosed and claimed in copending application, Serial No. 763,625, it is desirable materially to reduce the Q of a high-Q coil so to avoid the need to switch it out of circuit when it is desired to operate the receiver, transmitter or the like, in a frequency-band corresponding with a different coil. For frequencies substantially higher than those of the standard broadcast band and particularly for frequencies of the order of 100 megacycles or higher, it was found, contrary to expectations, that insertion of a solid metal core did not reduce the Q of a high-frequency coil to extent sufficient to permit it to remain connected in a frequency-determining circuit without materially affecting the resonant frequency of that circuit.

2

Referring to Fig. 1 by way of example, the curve 10, based on actual measurements, shows that the Q of a coil in which a core of cold rolled steel is inserted rapidly increases with increasing frequency and more and more approaches the normal high Q of the coil itself. Apparently as the frequency increases, there is increasingly less penetration of the magnetic field into the core or slug and the core losses consequently rapidly decrease with increase of frequency. A core made of cold rolled steel, drill rod, or the like, though satisfactory for use as a damping core at frequencies of the order of the standard broadcast frequencies or lower, is not suited for that purpose at substantially higher frequencies; and when the coil is to be comprised in a circuit tunable over a wide range, the increasing Q of the coil at the higher and higher frequencies introduces objectionable reactive effects. Specifically, as shown in Fig. 1, although the Q of the coil is about 5 at a frequency of about 1.8 megacycles, at a much higher frequency the Q of the coil is increased by a very substantial factor.

The use of non-magnetic metal or dielectric cores also has proven to be even more unsatisfactory because the electromagnetic flux of the coil is apparently repelled, or at least not enough of it penetrates the core to produce losses high enough to afford the desired damping.

In a damping core the stored energy per cycle varies as μH^2, whereas the dissipated energy per cycle varies as

$$\frac{\mu^2 H^2 f}{r}$$

wherein

μ=permeability
H=magnetization force
f=frequency
r=alternating current resistance.

From this relation, it would appear that maximum damping or maximum reduction of Q of the coil should be obtained when

$$\frac{r}{\mu f}$$

is made as small as possible to obtain high ratio of the dissipated energy to the stored energy. However, this is true only if the field penetrates all of the core material: actually the effective skin thickness of the core varies as

$$\sqrt{\frac{r}{\mu f}}$$

so that the optimum damping effect is in fact obtained at a compromise value

$$\frac{r}{\mu}$$

which is substantially higher than that based solely on the first relation above discussed.

It was found that by compressing a mass of finely divided iron, or like magnetic material, free of any binding material, into the desired core form and then sintering it at a temperature well below the melting point, there could be produced a core affording the desired high losses even at very high frequencies; and moreover, it was found that by suitable selection of the sintering temperature and the duration of its application to the core, there could be obtained a loss/frequency characteristic which remained constant over a wide band of frequencies, or which slowly increased with increase of frequency, or which slowly decreased with increase of frequency.

Preferably and by way of example, the core may be made of sponge iron powder whose particles can pass through a screen having a fineness of, for example, about 300 mesh and in any event not coarser than about 100 mesh and which are of random size and irregular shape. Apparently when a mass of such powder is subjected to high pressure usually not above 100,000 pounds per square inch as for example of the order of 50,000 pounds per square inch, the particles firmly interlock due to their irregularities so that the core retains its form after removal of pressure. The core so formed is then sintered at a temperature and for a time which markedly affect its resistive and magnetic properties, particularly at the higher frequencies.

By way of example, the Q/frequency curve 11 of Fig. 1 is produced by a compressed powdered iron core which was subjected to a sintering temperature of 800 degrees C. for twenty minutes. As apparent from the curve, the normally high Q of the associated coil was reduced to about 6 at a frequency of 1.8 megacycles and progressively decreased to a Q of about 3 at a frequency of about 118 megacycles. The high-loss core so formed is therefore well suited to dampen a coil to prevent it from exhibiting any substantial reactive or resonant effect over this wide frequency range.

The curve 12 of Fig. 1 resulted from insertion in the same coil of a core similar to that produced in curve 11 except that the sintering temperature of 800 degrees C. was applied for a period of about forty-five minutes. As shown by the curve, this core afforded a Q which was about 3 at a frequency of about 1.8 megacycles and slowly increased with increase of frequency, attaining a value of about 10 at a frequency of 118 megacycles. By comparison of the curves 10 and 12, it is evident that the powdered iron core so sintered affords substantially higher losses than those obtained by use of a solid magnetic core.

By inserting in the same coil a core of the same physical shape and dimensions which produced the curves 11 and 12 but which was sintered at a temperature of 800 degrees C. for thirty minutes, there was produced a high-loss core affording the Q/frequency characteristic shown by curve 13. As evident from Fig. 1, the high losses of this core remain substantially constant over the entire frequency range of from 1.8 megacycles to 118 megacycles and in fact well beyond

these limits and the core is therefore ideally suited for use as a damping core.

Neither the temperature nor the time is individually critical, but if the temperature is materially decreased, the period of its application must be increased, and vice versa, to obtain the same desired resistance (r) of the core. In brief, the resistance (r) may be decreased by increasing the molding pressure, by changing the fineness of the core powder, by increasing the sintering temperature or by increasing the sintering time. The permeability μ may be varied by selection of the iron. Thus a desired

$$\frac{r}{\mu}$$

may be obtained by suitable choice of any one of many combinations of pressure, temperature, time and materials so to predetermine the ratio of the stored magnetic energy of the core to the dissipated energy.

The temperature of 800 degrees C. provides for a suitably short sintering time, sufficient, however, for accurate control of the desired magnetic characteristics. If the sintering temperature is substantially increased above 800 degrees C., as for example to 1000 degrees C., the difference between the periods affording the different magnetic characteristics exemplified by curves 11, 12, 13 of Fig. 1 becomes so slight that obtainment of a particular desired damping characteristic is difficult to control. If, on the other hand, the temperature is reduced materially below 800 degrees C., for example to 500 degrees C., the sintering time is unnecessarily prolonged.

In résumé, the damping effect can be controlled or predetermined within wide limits by choice of the particle size of the powder, of the pressure applied in formation of the core, of the firing or sintering time, and of the sintering temperature. As these variables are interdependent, the value of any one or more of them may be chosen in view of other considerations such as availability, cost, or ease of control. From the general rules above and the specific examples herein given, those skilled in the art may readily produce and reproduce cores affording the desired damping characteristics.

As shown by curve 14 of Fig. 2, as a cold-rolled steel core approaches the open end of a coil normally having a Q of about 60 at a frequency of about 1.8 megacycles, the Q remains high and constant until the core is within a very short distance of the coil and then for continued movement of the core toward and into the coil, the Q rapidly falls to a low value which remains substantially constant as the core is further and further inserted. With the sintered powdered-iron core of the invention replacing the steel core, the resulting characteristic is shown by curve 15. As evident from Fig. 2, the curves 14 and 15 are generally quite similar at this relatively low frequency, but the sintered iron core affords a somewhat more rapid change of the Q at the beginning of its introduction into the coil and affords a somewhat lower Q throughout the range of its movement within the coil.

However, at materially higher frequencies, the Q characteristics of the coil when the cores are respectively of cold-rolled steel and sintered powdered iron are markedly different. Referring to curve 16 of Fig. 3, when the core is of cold-rolled steel and the applied frequency is about 118 megacycles the Q of the coil falls comparatively slowly as the core is inserted and at-

tains an objectionably high minimum of about 30 only after the core is well within the coil. As shown by curve 17, the insertion of a sintered-powdered iron core into the same coil affects a much more rapid change of the Q of the coil, and a low Q of about 5 is attained for only relatively slight insertion of the core.

The curves of Figs. 2 and 3 are based on measurements using cold-rolled steel and sintered powdered iron cores each having a length of one inch and a diameter of 0.246 inch. The coil used for Fig. 2 was one inch long, had an internal diameter of one-quarter inch and was wound of 220 turns of #37 wire: the coil was shunted with a 100 micro-microfarad tuning condenser. The coil used for the measurements of Fig. 3 was one inch long, one-quarter inch internal diameter and was wound of 5 turns of #18 wire. The shunt capacity in this case was 13 micro-micro-farads.

As apparent from curves 15—17 of Figs 2 and 3 and curves 11 to 13 of Fig. 1, a high-loss core of sintered powdered iron is capable of reducing to about the same very low value the Q of different coils operating at frequencies widely separated in the frequency spectrum. This characteristic, obtainable as above set forth in discussion of curve 13 of Fig. 11, is of particular value in switchless band-shifting arrangements such as disclosed in the aforesaid Carlson application and especially as when one and the same high-loss core is successively used with different coils corresponding to bands widely separated in the frequency spectrum. Referring, for example, to the multi-band amplifier circuit shown in Fig. 4, the coil 18 may be tunable by the low-loss core 19 through the range of standard broadcast frequencies, that is, from about 0.54 megacycle to about 1.6 megacycles and the coil 20 may be tunable by the low-loss core 21 through a substantially higher range of frequencies, for example, from 88 megacycles to 108 megacycles. The high-loss core 22, of powdered sintered iron, is inserted in the "low" band coil 18 when it is desired to tune through the "high" band, and is inserted in the "high" band coil 20 when it is desired to tune the "low" band. As indicated, the cores may be mechanically coupled for movement in unison so that throughout the range of movement for which the low-loss core 21 is effective to tune the coil 20 for operation in the "high" band, the high-loss core 22 is disposed within the coil 18 to maintain its Q, generally as discussed in connection with Fig. 2, at such low value that it exhibits no appreciable reactive effects. Conversely, when the core assembly is so moved that the low-loss core 19 is within coil 18 for tuning in the "low" band, the high-loss core 22 is movable within the "high" band coil 20 and throughout this range of movement is effective to maintain a very low and substantially constant Q of the coil 20 so that it does not affect the tuning. As evident from curve 16 of Fig. 3, the core 22 would not be satisfactory if of cold-rolled steel because with the core 19 in coil 18 for tuning in the "low" band, the coil 20, despite insertion of a cold-rolled steel core 22 therein, would have a substantial Q and the circuit would respond to signals in the "high" band.

As shown in Fig. 5, the coil and core arrangement of Fig. 4 may be used to provide a switchless multi-band oscillator which may be used as the local oscillator of a superheterodyne receiver, or for any other purpose. In the particular oscillator circuit shown, the "high" band coil 20A and

the "low" band coil 18A are connected in series between the grid 23 and anode 24 of an oscillator tube 25, the grid condenser 26 serving its usual function. The positive terminal B+ of a suitable source of anode current for the tube is connected to an intermediate point of the "low" band coil 18A. With the cores 19A, 21A and 22 in the position shown in Fig. 5, the coil 20A is tunable by the low-loss core 21A through, for example, a band of ultra-high frequencies. Throughout the range of tuning movement of the core 21A, generation of oscillations within the band corresponding with coil 18A is effectively prevented by insertion in the coil 18A of the high-loss core 22 of powdered sintered iron. For the "high" band, the oscillator functions as one of the Colpitts type and the "low" band coil 18A serves as a choke coil in the line to the anode current supply. For generation of oscillations in the "low" band, the cores are moved upwardly from the position shown in Fig. 5, so that the low-loss core 19A is movable within the coil 18A. Throughout the range of tuning adjustment of the core 19A, the generation of oscillations in the "high" band is prevented by the presence in coil 20A of the high-loss core 22. To insure that oscillations in the "high" band are not generated, the core 22, as evident from prior discussion, should be of powdered sintered iron, or equivalent, as otherwise the Q of the "high" band coil 20A may be sufficiently high despite insertion of the core to cause concurrent generation of both high and low-frequency oscillations.

In both the arrangements of Figs. 4 and 5, the high-loss cores 22 are movable in unison with the low-loss cores and it is therefore desirable that the Q of the coil corresponding with the non-selected band fall rapidly to very low magnitude as the high-loss core approaches it. This is insured for both the "high" and "low" bands when the core is of powdered sintered iron.

The use of powdered sintered iron cores for producing high losses in multi-band circuits is not limited to arrangements using low-loss cores, either of the magnetic or non-magnetic type, to effect so-called permeability tuning. For example, as shown in Fig. 6, the "low" band coil 18B and the "high" band coil 20B may be respectively tunable by the condensers 26 and 27, whose rotors may, if desired, be coupled for adjustment in unison. When the high-loss core 22 is within the "high" band coil 20B, the Q of that coil is so low that resonance of the circuit is determined by condenser 26 and its associated coil 18B, whereas when the damping core 22 is moved to within "low" band coil 18B, the resonance of the circuit is determined by condenser 27 and the "high" band coil 20B. Thus the composite circuit may be tuned by condensers 26, 27 to frequencies within either of the two bands simply by shifting the position of the high-loss core 22, thus avoiding the use of coil-switches with their attendant difficulties arising from variation of contact resistance of the switches, or of their inductance which is particularly significant at ultra-high frequencies.

In the preceding discussion, the damping effect of high-loss cores has been discussed in terms of the ratio between the energies respectively stored in and dissipated by the core and the damping effectiveness of the powdered cores of this invention has been correlated to factors controlling the effective resistance and permeability of the core. In supplement to that discussion, or as a different approach helpful to a better understand-

ing of relations involved, there is now discussed the circuit equivalent of a coil having a damping coil in its magnetic field.

The damping core and its coil may be considered the equivalent of two coupled circuits, Fig. 7, in which the coil L_3 and resistor R_1 correspond respectively with the inductance and resistance of the core and the coils L_1 and L_2 correspond respectively with the leakage inductance of the coil and with that fraction of its total inductance which has unity or 100 per cent coupling with the inductance L_3 of the core. The capacitor C represents the tuning capacity across the coil to be damped.

In further simplification; as the coupling between L_2 and L_3 is 100 per cent, they may, as in Fig. 8, be replaced by an equivalent inductance L directly shunted by a resistor R electrically equivalent to the resistance R_1 of the core. With solid magnetic cores, the leakage inductance L_1 of the coil increases with increase of frequency and so reduces the damping effect of resistance R even if the latter remained of constant value; however, with increase of frequency, the effective magnitude of resistance R decreases because of decreased penetration of the core. These effects are cumulative in effecting decreased core losses at the higher and higher frequencies with the result, as exemplified by curve 10 of Fig. 1, that the Q of the coil increases at undesirably high rate with increase of frequency.

On the contrary, with the sintered powdered iron cores of this invention, the leakage inductance L_1 of the coil is small throughout an extremely wide range of frequencies so that core resistance R may be considered as directly connected across the entire coil. Moreover with cores of such nature, the tendency of the eddy currents more and more to concentrate at the core surface with increase of frequency may be materially reduced, balanced or over-compensated so that, as exemplified by curves 12, 13 and 11 of Fig. 1, the Q of the coil is low throughout a very wide frequency range and either slowly increases or decreases with increase of frequency, or remains constant as predetermined by selection of the conditions of the core-forming process.

For a limiting condition of Q=1 at which the circuit exhibits no selectivity, the inductive reactance ($2\pi fL$) in ohms is numerically equal to the effective alternating current resistance (R) in ohms. Under this circumstance, the phase angle between the current in the coil and the current in the core is 45 degrees and the effective power factor of the coil is unity. With sintered powdered iron cores, this limit can be closely approached even at higher radio-frequencies for which other so-called high-loss cores of solid metal or solid dielectric are utterly ineffective.

Preferably in coil and damping core arrangements such as exemplified by Figs. 4 to 6, the high-loss core is disposed within the coil because the magnetic field is there the most intense. However, the core may be in the form of a case or cylinder closely fitting over the coil or may include both insertable and encasing members for the coil. Reverting to the plunger type of core, it need not be of continuous cross-section when the desired high-losses are attainable for skin depths which are less than the core radius or equivalent dimension: that is, in the case of cores having circular cross-section, the core may be a sleeve or tube whose thickness is about equal to the depth of penetration of the particular core at frequencies for which effective damping is desired.

It shall be understood that the invention is not limited to the specific methods and arrangements described and that changes and modifications may be made within the scope of the appended claims.

What is claimed is:

1. In combination, multi-band frequency-responsive signal circuits comprising a plurality of movable low-loss cores and coils corresponding to different frequency response bands for said circuits, a ferromagnetic core of powdered magnetic material subjected to a high pressure to form a suitable core shape and subsequently sintered at a temperature well below the melting point until a loss-versus-frequency characteristic is obtained in the core which is effective to dampen a high frequency inductor to prevent it from exhibiting any substantial reactive or resonant effect over a wide frequency range, means for progressively moving said ferromagnetic core into and moving one of said low-loss cores out of the magnetic field of one of said coils in unison, so that the tuning of one of said circuits is respectively damped and controlled in frequency response over a relatively wide frequency range.

2. In combination, a high frequency circuit, a tuning coil in said circuit, a ferromagnetic core movable for insertion in said coil, said core being constructed of powdered magnetic material subjected to a high pressure to form a core shape and subsequently sintered at a temperature well below the melting point until a loss-versus-frequency characteristic is obtained in the core which is effective to dampen said coil to prevent it from exhibiting any substantial reactive or resonant effect over a wide frequency range, a low-loss core movable for insertion in said coil to tune it through a predetermined frequency band, and means mechanically coupling said cores for unitary control and selective insertion in said coil, whereby said coil is effectively switched into and out of circuit when said ferromagnetic core is moved into and out of the field of said core.

ROBERT L. HARVEY.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,706,837	Bailey	Mar. 26, 1929
1,840,286	Hochheim	Jan. 5, 1932
2,191,151	Hale	Feb. 20, 1940
2,234,184	MacLaren	Mar. 11, 1941
2,276,832	Dome	Mar. 17, 1942
2,340,749	Harvey	Feb. 1, 1944
2,382,601	Boegehold et al.	Aug. 14, 1945
2,384,215	Toulmin	Sept. 4, 1945
2,386,604	Goetzel	Oct. 9, 1945
2,389,986	Koch	Nov. 27, 1945
2,402,260	Sands	June 18, 1946
2,407,234	Guthrie	Sept. 10, 1946
2,419,847	Mittermaier	Apr. 29, 1947
2,457,816	Grimm	Jan. 4, 1949

OTHER REFERENCES

Kalischer: "The Effect of Particle on Shrinkage of Metal Compacts," published in Symposium on Powder Metallurgy, 1943, pages 31 to 36.

Powder Metallurgy, published in Metals and Alloys, June 1942, pages 1025, 1026, 1028 and 1030.