

April 3, 1962

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3,027,628

MAGNETIC CORE AND METHOD OF MAKING THE SAME

Filed May 1, 1957

2 Sheets-Sheet 1

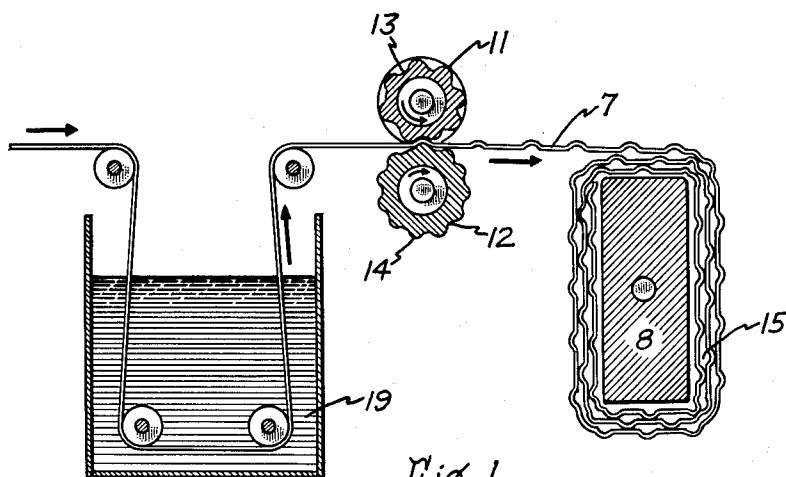


Fig. 1.

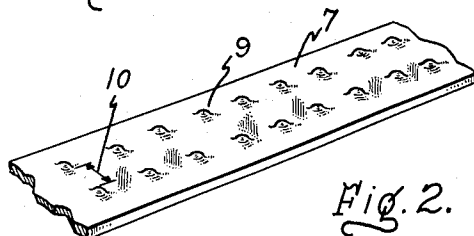


Fig. 2.

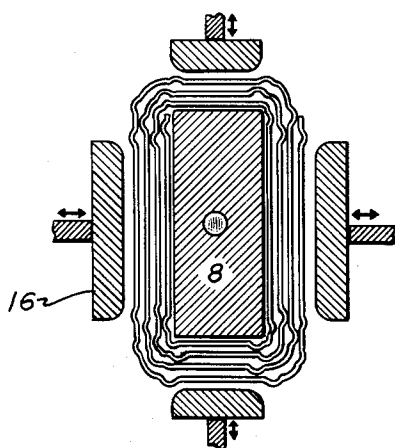


Fig. 4.

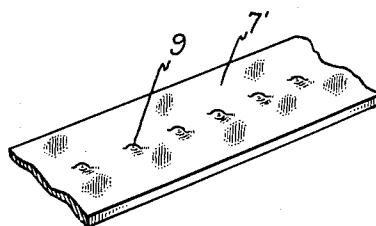


Fig. 3.

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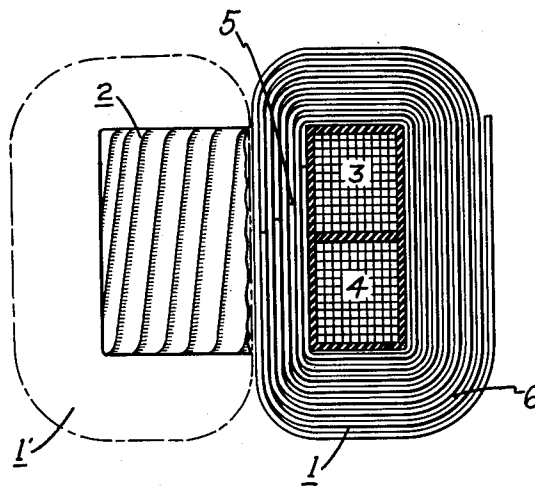


Fig. 5.

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3,027,628

MAGNETIC CORE AND METHOD OF MAKING THE SAME

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8 Claims. (Cl. 29—155.57)

This invention relates to a magnetic core, and more particularly, to wound magnetic cores and a method of making the same.

In the manufacture of one form of magnetic core a strip of magnetic material is wound into a closed loop of many turns. The core can be wound into a final rectangular configuration when this configuration is desired, or the loop can first be made annular or circular and then formed into a rectangular shape by forming dies.

Thereafter, the core is annealed and then the strip is unwound and cut into a plurality of strips of one or two turn lengths. The cutting operation is for the purpose of facilitating linking of the core with a preformed electrical winding or coil assembly. This is accomplished by lacing the plurality of cut strips through the electrical coils. If the core is unwound and cut from the inside the strips can be linked with the coils as they are cut. However, if the core is unwound and cut from the outside the strips will be linked inversely from the order in which they were cut.

It is intended that after the cut strips are linked with the coils the strips shall have the same positions they occupied with respect to each other as they had before the core was unwound and cut. However, this has been very difficult to achieve and looseness or gaps at the butt joints between the ends of the strips have resulted. One of the reasons for this is that the cut strips are deflected as they are laced with the coils and then it becomes very difficult to reassemble the various turns back into the same positions they occupied with respect to each other prior to unwinding and cutting.

Several solutions have been proposed to overcome these obstacles. One expedient has been to insert spacers between the turns during the winding operation. After the anneal the spacers are removed so that there is a desired degree of looseness between turns. This looseness facilitates the attainment of good butt joints after the core is unwound, cut and reassembled.

Some of the spacers have been metallic. Metallic spacers complicate the core manufacturing process and apparatus since means must be provided for inserting them, holding them in place, and then removing them.

Another type of spacer has taken the form of a paper strip which is simultaneously wound with the core strip between the turns thereof. This paper spacer is charred during the annealing operation. However, the conventional core strip is a low carbon content grain oriented silicon steel material. The carbon in the paper tends to contaminate the low carbon content steel strip whereas it is desirable to maintain a very low carbon content in the strip. Additionally, the charred paper must be cleaned out from the core by shaking or blowing and the like.

Another way to space the turns is to use a powder spacer. The powder spacer can be inserted between turns by depositing the powder on the strip. Although the powder composition can be such that it does not increase the carbon content of the strip during the annealing operation the problem of spacer removal is still present as well as that of dust control. Shaking the strip or directing blowers on the strip may not be sufficient to remove the powder spacer. The strip may need to be vibrated rather violently or washed to dislodge the powder spacer. Violent vibration of the strip may introduce distortions

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requiring another anneal, and washing is time consuming and requires drying and therefore increases manufacturing costs.

It is an object of our invention to provide an improved magnetic core and a method of manufacturing the same which will overcome the aforementioned disadvantages.

In one form of our invention an insulated strip of magnetic material has bumps or dimples formed along the length thereof at or near to the center thereof. The strip is wound into a closed magnetic core loop of many superposed turns. The bumps or dimples do not register or nest with respect to each other but serve as spacers between turns. All or less than all of the bumps or dimples are completely or less than completely collapsed by applying pressure to or annealing the core loop or both. Total or partial collapse of some or all of the bumps or dimples provides the necessary looseness between turns so that when the core is unwound, cut and rewound a compact core and firm butt joints are easily obtained.

Traces of the bumps or dimples which have been completely collapsed as well as bumps or dimples which have been only partially collapsed or not at all will minimize the increase of interlaminar eddy loss in the core due to impulse testing of the electrical windings or impulse conditions such as lightning surges. When the windings are impulsed the insulated laminations of the core are stressed. If an insulation breakdown occurs between laminations it will occur not along the edges of the laminations but at the bumps or dimples or their traces since all of these core parts are random points of high pressure contact. Short circuit loops across laminations at these points will result in lower interlaminar eddy core losses than if the short circuit loops occurred at the edges of the laminations since the former loops are shorter than the latter loops. This benefit of our invention is useful in plate cores as well as other wound cores which are not going to be wound, unwound, cut and then reassembled. Examples of such other wound cores are cores which will be wound and then cut and hinged open for linking with preformed coils, cores which will be wound circular and unwound and then rewound with preformed coils, and wound cores which will not be cut or unwound but will have the coils wound on the core.

Therefore, in an electrical apparatus comprising a magnetic core and linked electrical windings which may be exposed to impulse conditions, our invention comprises an improved core and a method of making and linking the same with electrical windings.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which we regard as our invention, it is believed the invention will be better understood from the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a diagrammatic illustration of one form of apparatus for performing the insulation coating, bumping and winding steps of our invention; and

FIG. 2 is a perspective view of the strip of FIG. 1 showing one arrangement of the bumps; and

FIG. 3 is a view similar to FIG. 2 showing another arrangement of the bumps; and

FIG. 4 is a diagrammatic illustration of one form of apparatus for performing the bump collapsing step of our invention; and

FIG. 5 is a diagrammatic illustration of the core loop of FIG. 4 after it has been annealed, unwound, cut and linked with the preformed electrical coils of one form of electrical transformer.

Referring now particularly to FIG. 5 of the drawing, illustrated therein is a transformer having a magnetic core 1 constructed in accordance with our invention. The core 1 is linked with a preformed electrical wind-

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ing assembly 2 which comprises primary and secondary winding sections 3 and 4 respectively.

One or more other magnetic cores 1' can be linked with the same electrical winding assembly 2. The winding assembly is hollow and one side of each of the cores passes through the hollow of the winding assembly. Said hollow is also known as the coil opening.

The core 1 has been cut every two turns as indicated by the butt joints 5 to facilitate linking of the core with the coil assembly 2. However, as will be more clear hereinafter the magnetic strip of the core can be cut into segments of more or less than one turn lengths or need not be cut at all in order to obtain the benefits of our invention.

The side of core 1 which passes through the coil opening is fairly compact so as to give as high a space factor as is possible. By high space factor is meant a high ratio of core material cross-sectional area within the coil opening to the cross-sectional area of the coil opening.

The laminations of the core on the other sides of the core and adjacent the corners are not compacted as snugly as along the side which is in the coil opening. The laminations of these other sides and corners have minute spaces 6 therebetween. These spaces have been exaggerated for purposes of clarity and they make it possible to link the cut turns with the coil so that they will have good butt joints 5 and occupy the same positions they occupied with respect to each other as they had before the core was unwound and cut. The manner of forming the core and providing the spaces 6 will be described in conjunction with FIGS. 1-4.

In FIG. 1 is shown an electrically insulated strip of grain oriented silicon steel magnetic material 7. The strip 7 is being wound on a rotating mandrel 8 whose configuration is similar to the desired core window opening and coil assembly cross-sectional outline illustrated in FIG. 5. However, the strip 7 does not have to be wound directly into a rectangular shape but it can be first wound round as into a circular shape. If this is done the round shape can then be formed into a rectangular shape by pressing. It is more difficult to wind a rectangular shape than a circular shape since with a rectangular shape special speed controls must be utilized to obtain uniform winding tension due to the corners and unequal sides of the rectangle. If the core is initially wound round its inner perimeter should have the same length as the inner perimeter of the rectangular shape which will thereafter be formed.

The strip 7 can be insulated by drawing it along a series of rollers through a liquid insulating material composition bath 19. However, the process does not have to be continuous and the strip can be coated at the steel mill before delivery to the transformer manufacturer. This bath deposits a very thin electrical insulating material film or coating on the strip 7.

Before the strip 7 is wound on the mandrel 8 it has a plurality of dimples or bumps 9 formed therein such as in the manner illustrated in FIGS. 2 and 3. It is these dimples or bumps which provide the spaces 6 mentioned heretofore with respect to FIG. 5. Ultimately they are partially or fully collapsed to provide the necessary looseness between core turns so that the ends of the cut core turns butt up firmly against each other at the butt joints 5 shown in FIG. 5. Therefore, it is necessary that the depressions 9 be of the correct size and configuration. They can be collapsed by the proper application of either pressure or heat and pressure. In the drawings the depressions 9 have been exaggerated for purposes of clarity. However, it will be obvious to those skilled in the art that in a core strip having a thickness of about 12 mils the height of the depressions may be of the order of about 1.5 mils.

If the depressions are too small they will not provide the necessary spacing. On the other hand, if they are too large they will introduce too much distortion into

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the strip 7. The same is true if they have sharp corners. A suitable configuration is to make them convex or concave with as gradual curves as possible near the crown thereof and in the portions thereof where they leave the general plane of the strip 7. The exact size and shape of the depressions will be dependent upon such factors as the size of the core, the amount of spacing required, the number of core turns and depressions, the collapsing pressures and the conditions of anneal.

The depressions need not necessarily be hemispherical but can be elongated and extend lengthwise, diagonally, or crosswise of the strip. However, they should be positioned away from the strip side edges and as close to the lengthwise centerline of the strip as practicable to obtain a minimum increase in interlaminar eddy core loss. For instance, if an insulation breakdown occurs across core laminations when the windings 2 are impulse tested or subjected to lightning surges the breakdown will occur at the depressions 9 or their traces after they are collapsed. This is because these depressions and traces are areas of high pressure contact between laminations. Such a breakdown usually occurs along the side edges of the laminations since they are sharper and more difficult to insulate from each other than the broad flat surfaces of the strip. However, the impulse stresses are transferred from the side edges to these depressions or traces assuming that the side edges have been properly deburred to remove any sharp burrs formed thereon during cutting of the strip.

If an insulation failure does occur between laminations the resultant short circuit loop in the core will be smaller than if failure took place at the edges of the strip. This is because the dimension 10 between adjacent depressions 9 of FIG. 2 is considerably shorter than the width of the strip. Interlaminar eddy current loops which extend transverse to the length of the strip may be omitted entirely by employing only a single string of depressions in line with the centerline of the strip as shown in FIG. 3.

The depressions 9 may be formed before the strip passes through bath 19 or after the strip leaves the bath and the coating thereon has dried. The means for forming depression 9 may comprise a pair of rollers 11 and 12 which rotate on opposite sides of the strip. The roller 11 has a plurality of external sockets 13 and the roller 12 has a plurality of free wheeling external balls 14. As the rollers 11 and 12 rotate the sockets 13 and balls 14 become aligned with each other to form the depressions 9. These depressions provide spaces 15 between successive turns of the strip and spaces 15 in turn provide and account for spaces 6 of FIG. 5. With grooves such as sockets 13 the two rollers 11 and 12 must move in synchronism. The necessity for synchronism can be avoided by forming an external circular groove in roller 11 opposite to each row of balls 14.

After the desired core build is obtained the core can be compressed to collapse the bumps 9. As shown in FIG. 4, four side acting dies 16 can be forced against the core sides to press the laminations thereof between the dies 16 and mandrel 8. In FIG. 4 the core is shown after its sides have been compressed whereby the bumps along the sides have been collapsed. Some of the bumps, and particularly those in the corners, will not have been collapsed by pressing. However, the strip can be bumped and wound in such a manner that no bumps are formed at the core corners. The core depicted in FIG. 4 can also be viewed as one which was initially wound round and then formed into a rectangular shape. Therefore, the step of pressing a round core into a rectangular one also results in collapse of the depressions. Additionally, in a round wound core the depression collapsing could be done before the round core was shaped into a rectangle. A circular core could be wound on a circular mandrel and a pressure roller could then be rolled around the outer perimeter of the circular core while it was still on its

circular mandrel. This would result in collapse of all of the depressions by external pressure so that none would be left even in the corners of the rectangle into which the circular core would thereafter be pressed.

After the pressing operation the core is placed in an annealing furnace to remove strains from the core and cause its turns to acquire a permanent set. Conventional core annealing procedures employ temperatures of about 800° C. or higher and our invention utilizes conventional core annealing processes and apparatus.

In our invention external pressing procedures as illustrated in FIG. 4 do not have to be depended upon to obtain collapse of the bumps but the annealing step can be depended upon solely for their collapse. This is because when a wound core is annealed it is braced while it is in the furnace. The wound turns tend to spring or bulge outwardly. If the core is not braced during the anneal the turns will then spring or bulge out so that the core will have a round shape instead of its intended rectangular shape after the anneal. For this reason when a rectangular core is annealed it is braced at least along the outer sides of its longer sides. This can be accomplished by special braces or by setting the core on one of its longer sides and weighting its other long side. When the core is braced the turns still tend to spring or bulge out but since the bracing resists this, inherent pressure is provided during the annealing operation. It is believed that the heat of the anneal relieves the stresses in the depressions and this inherent pressure is then able to at least partially collapse the depressions since annealing softens the steel. Therefore, in our invention only external pressure of the kind illustrated in FIG. 4 can be used for depression collapse, or a combination of the inherent pressure and heat of the annealing operation can be used to obtain collapse of the depressions.

It is believed that some depression collapse could be obtained even in a circular core by annealing alone if the circular core were externally banded. The external band would resist springing out of the turns. The necessary inherent pressure would thereby be created to obtain depression collapse in conjunction with softening of the steel and relief of the stresses in the depressions by the annealing heat. It is not believed that heat alone would collapse the depressions. For instance, if a bumped strip were heated the bumps probably would not be collapsed unless some external or inherent pressure were also applied to the heat strain relieved and softened bumps. Of course, external pressing before anneal and annealing with inherent pressure could both be used to obtain partial or total collapse of all or less than all of the depressions. Considerations such as core size, core turns, turn spacing, bump size, number of bumps, external and inherent pressures, type of bracing, and annealing temperatures will govern whether total or partial collapse of all or less than all of the bumps is necessary to provide the desired degree of looseness between turns so that the core can be properly laced with the electrical coils of an electrical apparatus such as a transformer. Therefore, by depression collapse is meant partial or total collapse of all or less than all of the depressions as well as total collapse of some of the depressions and partial collapse of some of the other depressions.

Our invention is useful in laminated cores even in the absence of the necessity of space between laminations for facilitating assembly of the cores with electrical coils. This is true of plate cores and strip wound cores of the hinged, C, and circular type. In these laminated cores our invention is useful for the purpose of minimizing the increase in interlaminar eddy core losses due to impulse stress conditions. Of course, if our invention is being used solely for this purpose then the bumps can be smaller and fewer in number so as not to decrease the space factor. However, even in this use of our invention some collapse of the depressions will be obtained even though this is not intended. This is because even these cores

are annealed with some inherent pressure due to bracing or their own weight. In these cases collapse of the depressions would be beneficial since this would make for a higher space factor and just traces of the collapsed depressions would be sufficient to provide random points of high pressure contact between laminations to minimize the increase in interlaminar eddy core loss due to impulse stress conditions.

Additionally, our invention is advantageous even where no depression collapse is obtained intentionally. For instance, in a wound rectangular core even depressions which are not collapsed at all will minimize the increase in interlaminar eddy losses. Furthermore, even though the depressions are not collapsed they would still permit easy rewinding of the strip. This is because the spaces provided by the uncollapsed depressions would reduce assembly friction between turns and thereby reduce creepage of the strip so that all turns could be rewound into their original positions. For instance, with uncollapsed depressions the surface distortions of one strip lamination would spring into or be taken up by the laminar space between that strip lamination and adjacent strip laminations.

After the anneal the strip 7 is unwound and linked with the winding assembly 2. The manner of doing this is well known in the art as illustrated by Vienneau Patent 2,305,649 which is assigned to the same assignee as the instant application. In FIG. 5 the core is illustrated as having been cut into two turn lengths. However, the core can be uncut or cut into lengths of less or more than one turn. These types of cores are likewise well known and illustrated by said Vienneau patent. The invention is useful with uncut cores as well as cut cores which are to be linked with preformed windings since when an uncut strip is unwound and then rewound on the windings there is creepage of the strip. This creepage builds up until the corners, curves and straight portions of the outer turns become too far out of line with the corresponding portions of the inner turns so that complete rewinding of the core turns back into their original positions becomes impossible. By virtue of the interlaminar spacing provided by this invention surface disturbances in the strip can be absorbed to permit free assembly of rewinding of the core with no creepage effects.

Also, it is within the scope of our invention to bump the core strip so that the spaces 15 are provided along less than all the sides of the core. For instance, the strip could be bumped so that spaces 15 appeared only along one of the shorter and longer sides of the core while still providing sufficient looseness between turns to obtain proper butt joints 5 and lacing of the strip with the coils 2. Also, the size of the bumps can be preselected and controlled such that no spaces 6 are present in the final core while still providing firm butt joints 5 and correct reassembly of the cut turns. However, this requires a very high degree of control and may result in some rejected cores and therefore may not be economically justifiable. Accordingly, it may be preferable to make the bumps large enough to provide for some looseness in the final core as indicated by the spaces 6.

Additionally, though the bumps 9 are shown as being uniformly spaced from each other this is not necessary nor for the purpose of having the bumps of succeeding turns nest or register with each other. If all of the bumps nested then they would not serve as spacers between turns and could not be collapsed by pressure. The uniform spacing between bumps is a result of uniform spacing between balls 14. The important consideration is that the bumps of immediately adjacent turns be located at random with respect to each other so that they do not nest but act as spacers.

The bump traces which are left after their collapse are hardly visible. However, they can be felt with the finger or seen if one is purposely looking for them. Nev-

ertheless, these traces are sufficient to provide random points of high pressure contact so that impulse breakdown does not occur along the edges of the lamination.

While there have been shown and described particular embodiments of the invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention, and therefore, it is intended by the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A method of manufacturing a wound magnetic core for a preformed electrical coil assembly of an electrical transformer comprising forming collapsible bumps in a strip of electrically insulated magnetic material away from the edges thereof, said bumps being formed solely in close proximity to the lengthwise center line of said strip, and winding said strip into a closed core having a plurality of superposed laminations which are spaced from each other by said bumps, and then collapsing said bumps while maintaining the spacing between said superposed laminations.

2. A method of manufacturing a generally rectangular shaped wound magnetic core for a preformed electrical coil assembly of an electrical transformer comprising forming a plurality of collapsible bumps in an electrically insulated strip of magnetic material away from the edges thereof, all of said bumps being formed as close as practical to the lengthwise center line of said strip, and winding said strip into a generally rectangular shaped closed core having a plurality of superposed laminations which are spaced from each other by said bumps and then collapsing said bumps while maintaining the spacing between said superposed laminations.

3. In a method as in claim 2, wherein said bumps are collapsed by applying pressure to said closed core.

4. In a method as in claim 2, wherein said bumps are collapsed by externally bracing and annealing said closed core.

5. In a method as in claim 2, wherein said bumps are collapsed by applying pressure to said closed core and then externally bracing and annealing said closed core.

6. A method of manufacturing a generally rectangular shaped wound magnetic core for a preformed electrical coil assembly of an electrical transformer comprising forming a plurality of collapsible bumps in an electrically insulated strip of magnetic material away from the edges thereof and solely along the lengthwise center line of said strip and winding said strip into a generally rec-

tangular shaped closed core loop having a plurality of superposed laminations which are spaced from each other by said bumps, and then collapsing said bumps while maintaining the spacing between said superposed laminations by applying pressure to said laminations and annealing said core loop while said core loop is closed.

7. A method of forming a generally rectangular shaped magnetic core which is linked with a preformed electrical coil assembly of an electrical transformer, said method comprising forming collapsible bumps in an electrically insulated strip of magnetic material solely along the lengthwise center line thereof and winding said strip into a generally rectangular shaped closed core loop whose laminations are spaced by said bumps, then applying pressure to said laminations and annealing said core loop while said core loop is closed and under pressure to collapse said bumps to effect interlaminar spacing between turns of said wound strip, and then unwinding said strip and reassembling it into said magnetic core while simultaneously lacing it with a preformed electrical coil assembly whereby said spacing will minimize mismatch of said turns in reassembly occasioned by creepage of the strip in said reassembly operation.

8. In an electrical transformer comprising a magnetic core and linked preformed electrical windings which may be exposed to impulse conditions, a method of forming said core comprising forming collapsible bumps in a strip of electrically insulated magnetic material away from the edges and solely along the lengthwise center line thereof and winding said strip into a closed core having a plurality of superposed laminations which are spaced from each other by said bumps, and then collapsing said bumps to provide interlaminar spacing between said laminations before said closed core is linked with said windings.

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