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3,480,499

METHOD OF MAKING LOW-VOID FILAMENT WOUND STRUCTURES

Filed Sept. 12, 1966

2 Sheets-Sheet 1

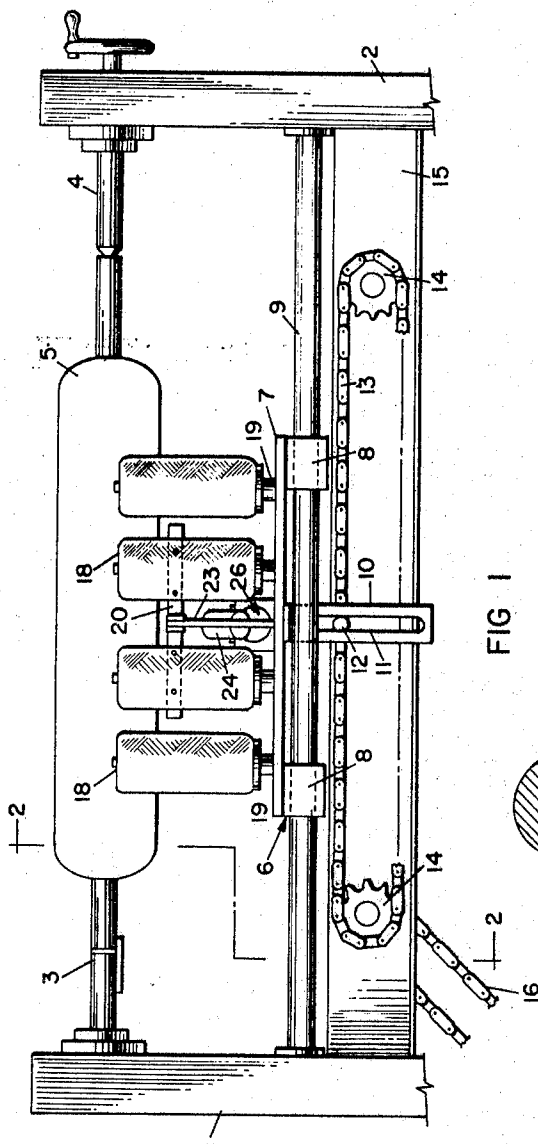


FIG 1

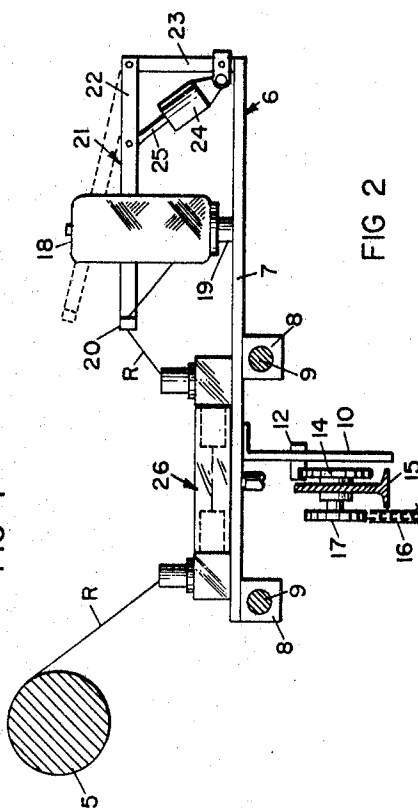


FIG 2

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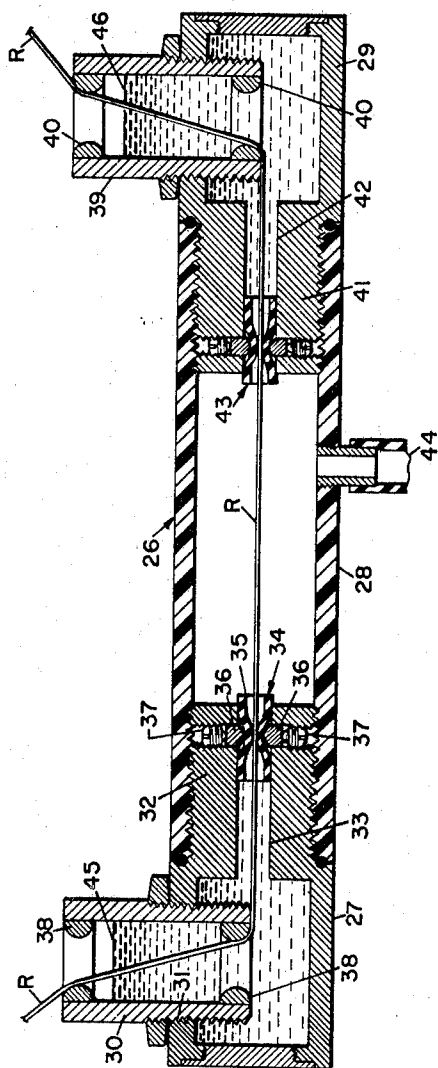


FIG 3

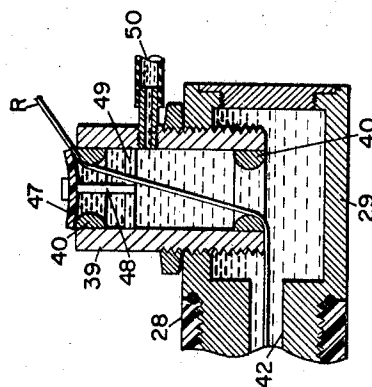


FIG 4

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1

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METHOD OF MAKING LOW-VOID FILAMENT WOUND STRUCTURES

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3 Claims

ABSTRACT OF THE DISCLOSURE

A process for making low-void filament wound structures wherein the roving is directed onto the rotating winding mandrel of a winding machine by means of a roving guide that traverses a path along the mandrel and directs the roving onto the mandrel in accordance with the predetermined pattern, the roving being passed through a vacuum chamber directly into immersion in a resin supply whereby the roving is substantially void-free prior to winding.

The present invention relates to a method of and apparatus for forming a filament wound article, and particularly to forming such an article with a reduced number and volume of voids.

The filament wound articles to which the present invention relates have a wall consisting of a wound fiber and a binding material, the fiber being of glass or other material that is characterized by a high tensile strength and light weight or, stated differently, a very high strength-to-weight ratio, and the binding material being a curable thermosetting resin, such as an epoxy polymer, which impregnates the windings and, when cured, becomes permanently set and thus binds the wound fibers into a self-supporting structure. These articles are designed primarily for use in applications requiring light weight as well as the capacity for withstanding high pressures or other stresses, such applications being for example a rocket case or the boom of a "cherry-picker," or the capacity for withstanding high electrical stresses as required for use in circuit breaker tubes.

In making filament wound articles, one method that has been widely used commercially is the so-called wet-winding process wherein the fiber in the form of a roving is first passed through a supply of the resinous binding material, which may be any suitable thermosetting resin that is liquid at room temperature and can be cured at temperatures within the tolerance of the fiber. The fiber or roving is thus wetted with the binding material and is thereafter wound, usually under tension, on a mandrel in accordance with the predetermined pattern. The binding material is then cured, after which the wound structure is separated from the mandrel, leaving a self-supporting structure having walls consisting of the wound fiber or roving bound together by the hardened binding material.

Filament wound articles heretofore produced by the wet-winding process may generally be characterized as including voids in the windings of between four and ten percent by volume, the voids being a local absence of binding material between adjacent filaments, either the adjacent filaments in a single turn of the roving or the adjacent filaments of successive turns of the roving. These voids have significant adverse effects upon the physical properties of the structure and particularly upon the inter-filamentary shear strength, that is, shear strength between adjacent filaments or longitudinally thereof, which strength can be increased by twenty-five to one hundred percent by elimination of the voids. In addition to in-

2

creasing the inter-filamentary shear strength, the reduction of voids in a filament wound structure also increases the dielectric strength thereof, thereby adapting the same for use in applications such as in the circuit breaker tubes of a power distribution system where electrical properties as well as high strength, light weight, inertness and/or thermal properties are important. Another significant characteristic of a low-void filament wound structure is its optical clarity. When the number of voids are reduced to a minimum, and assuming a compatible selection of glass fiber and binding material, the transparency of the structure is greatly improved, thereby rendering the structure useful in applications such as pressure tanks where seeing into the tank is important.

A primary cause of the voids is air carried into the wound structure by the roving and which cannot escape. This air is adhered to the surface of the fibers, trapped between the filaments thereof, and dissolved or dispersed in the resinous binding material with which the roving is wetted. The "rope pump" action of the roving as it moves rapidly into the supply of the binding material tends to increase to saturation the amount of air dissolved in the resin and also causes foaming or frothing, which forms fine bubbles that adhere to the surface of the roving. The air not only prevents wetting of the filaments by the binding material during impregnation of the roving but also expands during curing of the binding material because of the heat, which expansion tends to force the binding material out of the structure and to enlarge the void which is then fixed in the enlarged condition by the curing or setting of the binding material. The escape of the air from the inter-filamentary spaces is inhibited by the fineness of the filaments and by the encapsulation of the air bubbles by the binding material during impregnation. The viscosity of the resinous binding material also has a direct relation to the entrapment of air bubbles by the material, which viscosity can be reduced by heat but preferably should be reduced as little as possible in this manner since the heat also reduces the pot-life of the resin.

A further source of voids in wound structures are errors in the winding pattern which leave gaps between adjacent fibers of successive turns of the roving, or at crossing points of the windings in the winding pattern, or at the discontinuities that occur about inserts, such as the wafers for nozzle or port connections or reinforcing materials. Voids at the inserts can also result from poor wetting of the insert by the binding material whereby there is insufficient binding material provided for filling the resulting gaps.

Voids also result from an inadequate supply of resin in the wound structure either because of improper coating or impregnation of the roving or because of handling the impregnated roving before winding or of the wound structures after winding. Scraping or otherwise removing excess material from the roving before winding may remove too much of the material so that there is an insufficient amount to fill the inter-filamentary spaces in the wound structure. In scraping the wound structure while it is still wet and soft, the localized pressure of the scraping tool may squeeze out too much of the resin so that when the pressure is suddenly removed, the windings quickly recover to their normal condition and produce voids that fill with air. A further source of voids is the drainage of the binding material from the wet wound structure. The extent of the drainage depends upon the length of time that the wound structure was allowed to stand, its orientation, and the viscosity of the resinous binding material, which of course is temporarily reduced by heating during the initial stages of the curing.

The amount of voids in a filament wound structure also varies with other factors that affect the penetration of

the binding material into the roving, such as the compactness of the roving or the condition of the fiber. As examples, the fiber may have a finish that inhibits or promotes wetting by the binding material or may have filaments that have become bonded together during storage and that form barriers to the penetration of the resin into the underlying fibers.

Prior commercial efforts to eliminate voids in a filament wound structure have centered around the use of tension on the roving during winding to compact the windings and thus force out the air, the use of heat to reduce the amount of air that is dissolved in the resin and to facilitate the escape of the air pumped into the resin supply by the "rope-pump" effect, and the use of pressure during curing to reduce the bubbles by physically compressing them and by increasing the solubility of the air in the resin to dissolve the air from the bubbles. There has also been an experimental proposal to reduce voids by mounting the winding apparatus in a vacuum chamber. None of these approaches has been completely successful and all have disadvantages, such as for example, heating reduces the pot life of the resin, or pressure curing requires massive and expensive equipment and is only partially successful in removing the voids, or winding in a vacuum requires expensive equipment and is difficult to control because of the inaccessibility, both visually and physically, of the windings.

The primary object of this invention is to provide a process and apparatus for making a filament wound structure having a reduced number of voids and therefore having increased strength, particularly inter-filamentary shear strength and compressive strength, and having improved optical clarity and electrical properties, which process and apparatus involve a minimum investment in equipment, is simple to operate, is economical, dependable and trouble-free in operation, and which is effective in producing the desired results.

In accordance with this invention, the above objects have been attained by treating the roving prior to winding to remove or to reduce the air adhered to the surface or encapsulated or dissolved in the resin, as well as that which is trapped within the inter-filamentary spaces of the roving. Specifically, the invention resides in passing the roving continuously from a vacuum chamber directly into immersion into a resin supply for impregnating the roving with resin. With existing winding machines substantially void-free filament wound structures operating in the normal manner, can be produced simply by substituting the present resin supply for the usual resin cups.

One of the significant features of this invention is that, in addition to the removal of the air from the surface and the inter-filamentary spaces of the roving, the roving passes from the vacuum directly into the supply of impregnating resin so that there is no air carried into the resin supply by the "rope-pump" action of the roving. The resin supply thus remains clear and relatively air-free during the entire operation, which is in contrast to the condition of the resin supply in a normal wet-winding operation wherein the resin supply becomes completely clouded by frothing or the dispersion of minute air bubbles throughout the supply almost immediately at the beginning of the winding operation.

With the above and other objects in view, a preferred embodiment of the present invention is hereinafter described with reference to the accompanying drawings, in which:

FIG. 1 is a fragmentary elevational view of a winding machine embodying the present invention.

FIG. 2 is a fragmentary sectional view taken substantially on the line 2—2 of FIG. 1.

FIG. 3 is a detailed vertical sectional view longitudinally of the vacuum impregnator for the roving of the machine of FIG. 1.

FIG. 4 is a fragmentary detailed view in section of a modification of the present invention.

With reference to the drawings, there is illustrated somewhat schematically in FIG. 1 a winding machine having end supports 1 and 2 with winding spindles 3 and 4 for releasably receiving the rotating mandrel 5 upon which the filament wound structure is to be wound. To rotate the mandrel 5, it is coupled for rotation to the spindle 3 which in turn is driven by drive means (not shown) housed in the end support 1.

A roving carriage 6 is adapted to traverse back and forth along the mandrel 5 to feed resin-impregnated roving onto the mandrel. The illustrated carriage 6 comprises a platform 7 having bearing lugs 8 that are slidably mounted on a pair of supporting rods 9 extending between the end supports 1 and 2 and having the axes thereof parallel to the axis of the mandrel 5, whereby the platform 7 is supported for movement in a path parallel to the axis of the mandrel 5. For driving the carriage 6 back and forth along the rods 9, there is an arm 10 depending from the platform 7 and having a vertical slot 11 that receives the drive pin 12 of a drive chain 13. The chain 13 is entrained about a pair of sprockets 14 that are journaled on a cross piece 15 extending between the end supports 1 and 2, the sprocket 14 adjacent to the end support 1 being driven by a chain 16 entrained about a sprocket 17 (FIG. 2) and about a drive sprocket (not shown) housed within the end support 1. The chain 13 with its pin 12 cooperates with the arm 10 in the manner of a scotch yoke to drive the carriage 6 back and forth as the chain is driven.

The platform 7 carries a plurality of spools 18 of roving which are mounted on frictioned spindles 19 upstanding from the platform 7 and which impose a selected resistance to rotation of the spools 18 whereby a predetermined tension is imposed on the roving as it is drawn from the spools. From the spools 18 the roving R passes to a roving guide 20 of a take-up mechanism 21 that is designed to take up the slack in the roving as the direction of travel of the carriage 6 is reversed at the end of each stroke, that is, as the pin 12 passes around one of the sprockets 14. The take-up mechanism 21 comprises an arm 22 having the guide 20 at one end thereof and being pivotally mounted at its other end to a bracket 23 upstanding from the platform 7. A constant bias is imposed upon the arm 22 to move the free end thereof, i.e., the end carrying the guide 20, in the direction to take up slack in the roving, which is toward the dotted line position in FIG. 2. The means for biasing the arm 22 comprises an air cylinder 24 that is pivotally mounted at one end to the bracket 23 and has the piston rod 25 thereof pivotally connected to the arm 22. When the roving is under normal tension as it is when being drawn from the spools 18 during winding, the arm 22 is deflected to the full line position illustrated in FIG. 2.

From the roving guide 20 at the end of the take-up arm 22, the roving R passes into an impregnator 26 comprising an entry chamber 27, a vacuum chamber 28, and an exit chamber 29. The entry chamber 27 has an externally threaded inlet tube 30 that extends through a threaded opening 31 in the top of the chamber 27 and a cylindrical extension 32 extending laterally from one side thereof. The extension 32 includes an axial bore 33 that serves as a roving passage and which is provided with a resin seal 34 that provides for passage of the roving from the entry chamber into the vacuum chamber 28, but which restricts the leakage of resin into the vacuum chamber and which seal 34 constitutes the inlet seal for the vacuum chamber. As illustrated, the seal 34 may comprise a short section of soft rubber tube 35 inserted into the end of the bore 33 and adapted to be collapsed or pinched onto the roving by a pair of opposed slides 36 seated in slots in the cylindrical extension 32 and movable toward and away from each other by means of adjustment screws 37. The inlet tube 30 has toroidal guides 38 that are semi-circular in cross-section and are mounted at both the input and the output ends thereof to minimize the abrasion of

the roving as it passes the edges of the tube upon entering and leaving the same. The inlet tube is threaded into the entry chamber until the lower end thereof is substantially at the level of the midpoint of the bore 33 whereby the roving will pass directly into the bore 33 without contacting the edges thereof.

The exit chamber 29 is substantially the same as the entry chamber 27 and includes an outlet tube 39 with toroidal roving guides 40 at the top and bottom thereof, and a lateral extension 41 having a bore 42 through which the roving passes and which is provided with a seal 43 for preventing resin from leaking from the exit chamber into the vacuum chamber 28 while at the same time permitting the roving to pass from the vacuum chamber 28 into the exit chamber 29.

The vacuum chamber 28 comprises a tubular section that surrounds and is secured to the extensions 32 and 41 of the entry chamber 27 and exit chamber 29, the section, for example, being threaded onto the sections as shown in FIG. 3. A vacuum line 44 is connected to the vacuum chamber 28 at one end and at its other end is connected to a source of vacuum (not shown). The amount of vacuum imposed on the vacuum chamber 28 is not critical and it has been found that a vacuum in which the absolute pressure is in the range of ten to twenty millimeters of mercury is adequate as well as economical to maintain.

The entry chamber 27 and its input tube 30 are filled with resin to the level indicated at 45 and are maintained full to a level within the inlet tube 30 whereby the roving R will be wetted within the resin before contacting the roving guide 38 at the bottom of the inlet tube 30. In the same manner as in the usual wet-winding processes, as the roving moves into the inlet tube 30, it pumps entrained air into the resin and also sets up a circulation pattern in the resin so that the resin is thoroughly mixed with air bubbles. Most of this air can be removed in the same manner as heretofore used in wet-winding processes, that is, by heating the resin to reduce its viscosity and thus facilitate escape of the trapped air. With the present system, the residue of this air, or all of it when using resins that cannot tolerate prolonged heat, is readily removed in the vacuum chamber 28. While there is some resin impregnation of the roving in the entry chamber 27, the primary purpose of the chamber 27 is to wet the roving with resin so that it is well lubricated before it passes over the lower guide 38 and through the seal 34, thereby reducing abrasion and assisting in maintaining the integrity of the seal 34.

Upon passing through the seal 34 and into the vacuum chamber 28, the roving R is subjected to the vacuum and is immediately purged of the air adhered to the surface thereof and trapped in the inter-filamentary spaces thereof. At the same time, because of the reduced pressure, air dissolved in the resin or encapsulated therein is also released.

From the vacuum chamber, the roving R passes through the seal 43 into the exit chamber 29 and exits from the chamber 29 at the roving guide 40 at the top of the outlet tube 39. The chamber 29 is normally filled with resin to a level above that of the bore 42, that is, to a level within the outlet tube 39, such as the level 46 as illustrated. Inasmuch as the roving is substantially evacuated of air in the vacuum chamber 28, it is immediately thoroughly impregnated by the resin in the exit chamber 29 which is at atmospheric pressure. The resin in the exit chamber may, if desired, be de-gassed prior to use. Since the roving entering the chamber is substantially evacuated and, entering from a vacuum, there is no tendency for the roving to entrain or pump air into the resin. Also, since the roving is partially wetted with resin from the entry chamber 27, which resin was substantially flashed in the vacuum chamber, there is a reduced amount of resin from the exit chamber required to saturate the roving.

In order to help maintain the level of the resin in the entry chamber 27 and in the exit chamber 29, resin reservoirs (not shown) may be connected to them. A further advantage of such a reservoir is that it provides a relatively wide and easy to fill opening, whereas the openings defined by the guides 38 and 40 at the upper ends of the inlet tube 30 and outlet tube 39 are designed primarily for controlling the lead of the roving and may be quite small.

In operation, in the usual manner, the roving carriage 6 is moved back and forth along the mandrel 5, which, as it rotates, draws roving from the supply spools 18, through the impregnator 26 and out the roving guide 40 at the top of the outlet tube 39. The pattern in which the roving is laid on the mandrel is a function of the speed of rotation of the mandrel relative to the speed at which the carriage 6 is traveling. Preferably, the speed of the mandrel 5 is variable so that the winding may proceed at a relatively rapid rate, while the speed is substantially reduced when the direction of travel of the roving carriage 6 is reversed at the end of each stroke, to prevent excessive twisting of the roving.

Substantially void-free roving has been produced in accordance with this invention at roving speeds of up to two hundred feet per minute. Such roving, when wound into a filament wound structure, produces a substantially void-free structure.

In addition to the fact that substantially void-free windings are produced by the present invention, a further advantage is that it requires a minimum investment in equipment. Most winding machines in operation today have a roving carriage that traverses a path along the mandrel and carry a supply of roving that is led to the mandrel through a resin cup. The present invention can be practiced on such equipment by replacing the resin cup with a vacuum impregnator for the roving as herein disclosed. It will, of course, be apparent that the specific details of the mechanism disclosed are not essential to the invention in its broadest aspects and, in particular, the exit chamber 29 could be made to deliver the roving downwardly rather than upwardly by substituting a resin chamber such as that which forms the subject matter of the Young Patent No. 3,025,205 for that disclosed herein, the substitution requiring only that the roving pass directly from the vacuum chamber into the resin chamber at a point below the level of the resin and therefore passes directly into the resin.

While the outlet tube 39 may be open to the atmosphere at its upper end as illustrated in FIG. 3, so that the roving passes out of the resin supply, this arrangement with some resins permits the roving to carry an excess of resin over that which can be used in the winding. This excess not only represents a waste of resin but also presents a problem in collecting it and in preventing it from being thrown about. To reduce the quantity of resin on the roving to a minimum in excess of that which is required to saturate the windings, the outlet tube may be provided with a flap or flexible seal 47 as illustrated in FIG. 4. The seal 47 overlies the open area defined by the guide 40 at the outlet of the tube 39 and is held in position by a shoulder screw 48 that is threaded into a spider 49 in the tube 39. The roving R is designed to pass outwardly between the guide 40 and the seal 47 whereby the relatively light pressure of the seal on the roving tends to wipe the roving and to return some of the resin thereon to the reservoir. A further advantage of the seal 47 is that it closes the top of the tube 39 and thus permits filling the tube 39 completely with resin. In this manner, the tube 39 can be connected to an external resin reservoir, as by the conduit 50, which has a head greater than that in the tube 39 without overfilling or spitting the resin from the tube.

I claim:

1. In a method of making a filament wound structure from a roving that is characterized by high tensile strength

7

and light weight and a binding material that consists of a curable thermosetting resin, said method comprising the steps of impregnating a continuous length of said roving with said resin by passing the same through an impregnator, guiding the resin-wet roving to a roving guide, moving the roving guide and impregnator along a path parallel to the axis of the rotating mandrel of a winding machine, actuating said roving guide along said path in accordance with a predetermined pattern for winding the roving onto said mandrel in accordance with said predetermined pattern, and curing said resin to bind the wound roving into a filament wound structure, and wherein, in the step of impregnating said roving, said roving is passed continuously in the impregnator through a seal into a vacuum chamber for substantially evacuating the air from the inter-filamentary spaces and from the surface thereof, from the vacuum chamber through a seal directly into immersion in a resin supply, and from said resin supply to the atmosphere, whereby the resin-wet roving guided to said roving guide is substantially void-free.

8

2. The method of making a filament wound structure in accordance with claim 1 wherein said roving is pre-impregnated with resin prior to passing from said vacuum chamber through said seal and into immersion in said resin supply.

3. The method of making a filament wound structure in accordance with claim 1 wherein said roving is passed from the atmosphere into immersion in an initial resin supply prior to being passed through the seal into the vacuum chamber.

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PHILIP DIER, Primary Examiner

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117—119; 118—50, 405; 156—285, 382; 220—3