Sept. 13, 1960 J. J. ZIMSKY 2,952,068

METHOD OF CONSTRUCTING MAGNETIC CORES

Filed Jan. 4, 1957 2 Sheets-Sheet 1

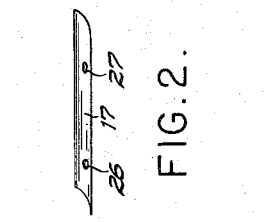

FIG. 2.

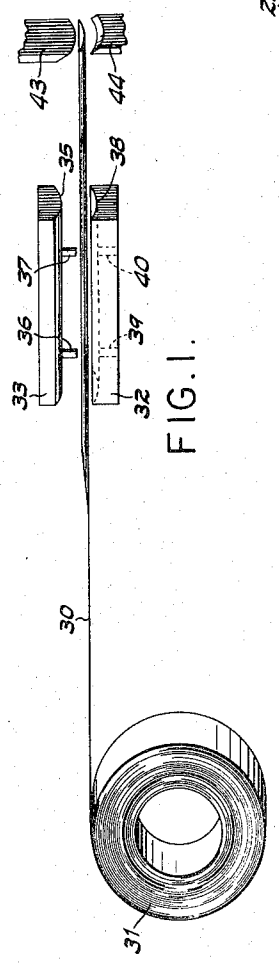

FIG. 1.

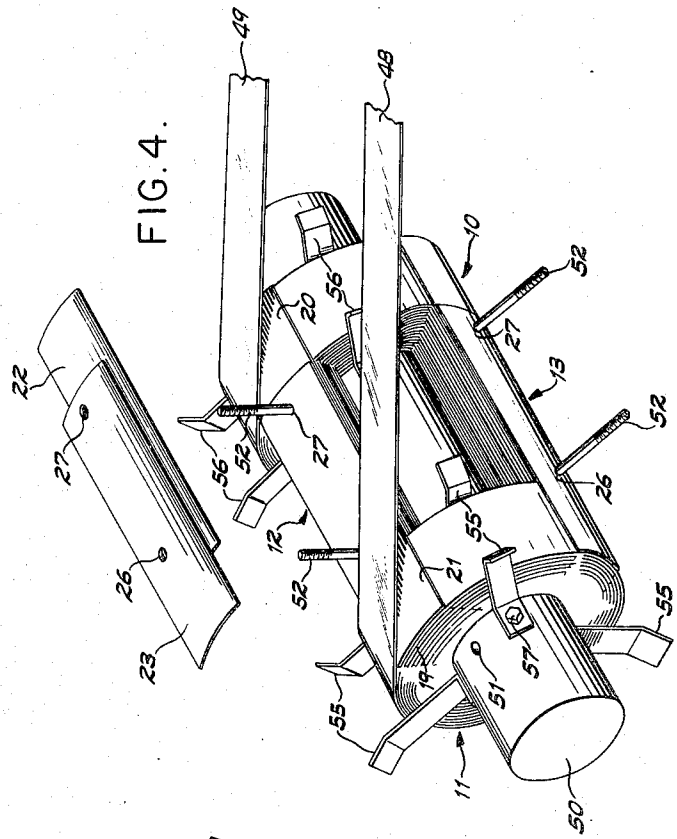

FIG. 4.

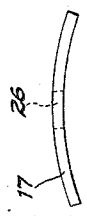

FIG. 3.

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FIG. 5.

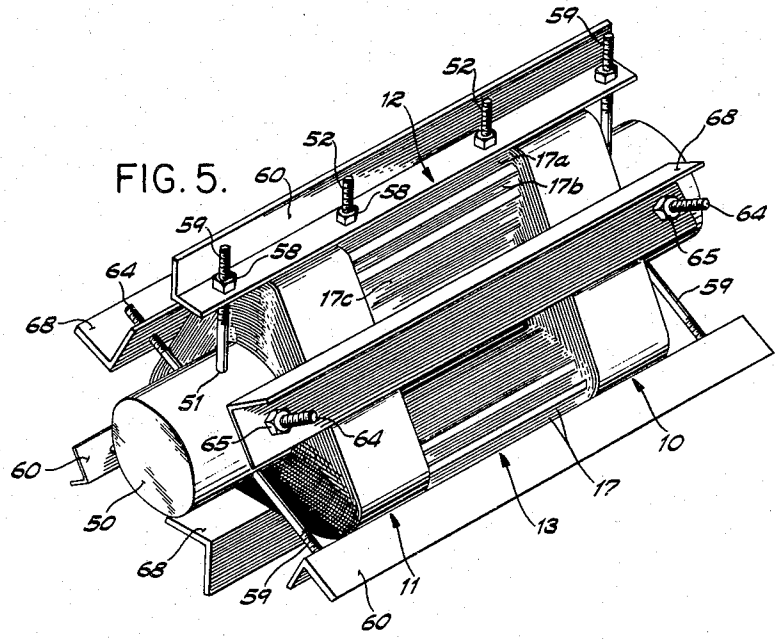
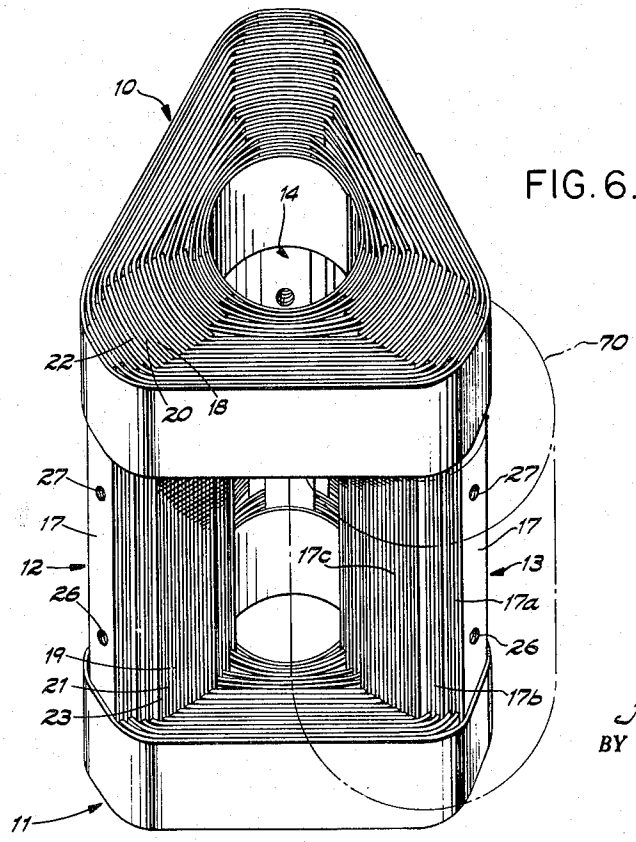


FIG. 6.



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METHOD OF CONSTRUCTING MAGNETIC CORES

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6 Claims. (Cl. 29—155.57)

This invention relates to magnetic cores for stationary induction apparatus and more particularly to a method of constructing three phase magnetic cores of the delta yoke type.

In a delta yoke magnetic core a pair of generally hexagonal, multi-turn, laminated yoke members coaxially spaced from each other are interconnected by three symmertically spaced, parallel, laminated leg members. When both yoke members are of spirally wound continuous magnetic strip, it is difficult to assemble the upper yoke to the leg laminations, particularly in delta yoke cores for transformers of large kva. rating. In the assembly procedure conventionally followed, vertically disposed leg laminations are first interleaved with the turns of the continuous strip lower yoke while the latter is positioned in a horizontal plane. Subsequently the relatively heavy and bulky, continuous strip upper yoke is suspended in a horizontal plane and lowered into position above the leg members, and the leg laminations are interleaved with the spiral turns while the upper yoke is held in this raised position. This interleaving of the ends of the leg laminations between turns of the upper yoke while the latter is suspended in a horizontal plane is tedious and difficult to accomplish and is costly both in time and labor.

It is an object of the invention to provide a novel method of constructing three phase magnetic cores and assembling stationary induction apparatus.

It is a further object of the invention to provide an improved method of constructing three phase delta yoke magnetic cores which is more efficient and economical than prior art methods.

Other objects and advantages of the invention will be apparent from the following description when taken in conjunction with the accompanying drawing wherein:

Fig. 1 is a perspective view illustrating the method step of forming leg laminations;

Fig. 2 is a perspective view of a leg lamination formed by the step illustrated in Fig. 1;

Fig. 3 is an end view of a leg lamination formed in accordance with the step illustrated in Fig. 1;

Fig. 4 is a perspective view illustrating the method step of spirally winding two continuous strips of magnetic ribbon simultaneously to form two yoke members and concurrently assembling straight leg laminations between yoke turns during the winding thereof;

Fig. 5 illustrates a preferred means of holding the wound yoke turns having straight leg laminations interleaved therewith during annealing; and

Fig. 6 is a perspective view of a delta yoke transformer constructed in accordance with the method of the invention.

Referring to the drawing and more particularly to Fig. 6, a delta yoke magnetic core constructed in accordance with the method of my invention includes a generally delta-shaped, or hexagonal-shaped, multi-turn upper yoke member **10** coaxially spaced from and interconnected to a generally delta-shaped, or hexagonal-shaped, multi-turn lower yoke member **11** by each of three laminated, symmetrically spaced apart, parallel leg members **12**, **13** and **14**. The upper and lower yoke members **10** and **11** are substantially identical and each comprises a multi-turn, generally delta-shaped loop of spirally wound continuous magnetic ribbon having a preferred direction of magnetization lengthwise thereof. In the illustrated embodiment the magnetic strip is of constant width throughout each yoke member **10** and **11** and further is of the same width in the upper and lower yoke members **10** and **11**, but it will be apparent that each of the yoke members may be constructed, if desired, of successive, different width strips to provide a cruciform cross section.

Each leg member **12**, **13**, and **14** comprises a plurality of straight, contiguous, leg laminations **17** of magnetic strip material having a preferred grain orientation lengthwise thereof. In order to provide leg members **12**, **13** and **14** of cruciform cross section, the leg laminations **17***a*, **17***b*, and **17***c* are of different widths with the narrowest laminations **17***a* disposed at the radially inner and outer edges of the legs **12**, **13** and **14** and the widest laminations **17***c* disposed centrally of the leg members **12**, **13** and **14**. In the illustrated magnetic core all of the leg laminations are of equal length, but the ends of successive laminations are staggered so that alternate laminations, e.g., **19**, **21**, **23** etc., have their ends extending beyond the ends of the intermediate leg laminations, e.g., **18**, **20**, **22** etc., at one end of each leg member, e.g., leg member **12**, and the intermediate leg laminations **18**, **20**, **22** etc. extend beyond the ends of the alternate leg laminations **19**, **21**, **23** etc. at the opposite end of leg member **12**. The extending ends of the alternate leg laminations **19**, **21**, **23** etc. fit between the turns of the lower yoke member **11** and the ends of the intermediate leg laminations **18**, **20**, **22** etc. abut against the turns of the lower yoke **11**. Similarly the extending ends of the intermediate leg laminations **18**, **20**, **22** etc. are interleaved with the turns of the upper yoke member **10** and the ends of the alternate leg laminations **19**, **21**, **23** etc. abut against the turns of the upper yoke member **10**. Each leg lamination **17** is provided with two locating holes **26** and **27** therethrough. The locating hole **27** is adjacent to one end of leg lamination **17**, and the locating holes **26** in all of the alternate laminations **19**, **21**, **23** etc. in each leg are in register with the locating holes **27** in all of the intermediate laminations **18**, **20**, **22** etc., and similarly the locating holes **27** in the alternate leg laminations in each leg member are in register with the locating holes **26** in all of the intermediate laminations. Preferably each of the leg laminations is of arcuate cross section (see Figs. 2 and 3) to facilitate compact nesting thereof.

In the preferred mode of practicing the invention, the leg laminations **17** are constructed in the manner illustrated in Fig. 1 wherein continuous strip magnetic material **30** having a direction of easiest magnetization lengthwise thereof is advanced longitudinally from a supply roll **31** by suitable feed means (not shown) and shaped to arcuate cross section and simultaneously formed with two locating holes **26** and **27** therethrough in a piercing and shaping die having a perforated matrix **32** and a cooperating punch **33** reciprocable relative to each other. The lower surface **35** of punch **33** is convex in cross section, and the punch **33** is provided with two depending piercing bosses **36** and **37**. The upper surface **38** of matrix **32** is concave in cross section and complementary to the lower surface **35** of punch **33**, and two spaced apart perforations **39** and **40** provided through matrix **32** are adapted to receive the piercing bosses **36** and **37**. When magnetic ribbon **30** is advanced between punch **33** and matrix **32**, and the cooperating punch **33** and matrix **32** are reciprocated relative to each other, the magnetic strip **30** is formed to

arcuate cross section and two locating holes 26 and 27 are punched therethrough by the piercing bosses 36 and 37.

A shearing device having cooperating knife members 43 and 44 reciprocable relative to each other is adapted to cut the continuous magnetic strip 30 into leg laminations 17 of desired length after the strip has been formed to arcuate cross section and the holes 26 and 27 punched therein by punch 33 and matrix 32, and preferably means (not shown) are provided to operate the strip feeding means (not shown), the punch, and the shearing device in synchronism to automatically shear magnetic ribbon 30 into leg laminations 17 of desired length.

As shown in Figs. 2 and 3 each leg lamination 17 is arcuate in cross section and has two locating holes 26 and 27 therethrough spaced apart longitudinally of the lamination 17.

The leg laminations 17 are assembled concurrently with the forming of delta yoke members 10 and 11. Two continuous strips 48 and 49 of magnetic ribbon, preferably of the same width, are simultaneously wound at axially spaced apart positions on a rotatable mandrel 50 as shown in Fig. 4 to form yoke members 11 and 10, and concurrently with the winding three leg laminations 17 are inserted between the wound turns of each of the strips 48 and 49 during each 360 degrees of rotation of mandrel 50. During the winding of yoke members 10 and 11 the leg laminations 17 are positioned in radially aligned piles constituting the legs 12, 13 and 14 of the final core, and the alternate leg laminations 17 at opposite ends of each leg 12, 13 and 14 are interleaved with the wound turns of each of the delta yoke members 10 and 11. Cylindrical mandrel 50 is provided with threaded apertures 51 arranged in sets spaced approximately 120 degrees apart about its circumference and adapted to receive radially extending locating studs 52 for guiding the leg laminations 17 during assembly. As shown, each set includes four axially spaced apart apertures 51 positioned in a plane coincident with the axis of mandrel 50. Three pairs of studs 52 spaced approximately 120 degrees apart and threaded within the apertures 51 of each set between the ribbons 48 and 49 are adapted to project through locating holes 26 and 27 in the leg laminations 17.

Pairs of radially extending guide brackets 55 bolted at axially spaced positions on the outer periphery of mandrel 50 guide the continuous magnetic strip 48 during winding to assure that all turns of lower delta yoke member 11 are disposed in a radial plane, and similarly pairs of radially extending guide brackets 56 bolted at axially spaced positions on the outer periphery of mandrel 50 guide the continuous magnetic strip 49 to assure that all turns of the upper delta yoke member 10 are disposed in a radial plane. Preferably the threaded apertures in mandrel 50 for receiving the bolts 57 which secure brackets 55 and 56 to mandrel 50 are located between the sets of apertures 51. The leg laminations 17 are assembled so that the studs 52 extend through the locating holes 26 and 27 and with successive leg laminations 17 staggered so that the ends of alternate laminations 19, 21, etc. are inserted between the turns of lower yoke 11 wound on mandrel 50 and so that the ends of laminations 18, 20, etc. intermediate the alternate laminations 19, 21, etc. are inserted between the turns of upper yoke 10 wound on mandrel 50. As illustrated in perspective in Fig. 4, the alternate leg lamination 23 will be inserted over the locating studs 52 so that the one end of lamination 23 will overlap continuous strip 48 and the opposite end of lamination 23 will abut against the edge of the turn of strip 49. The intermediate leg lamination 22 will be inserted over locating studs 52 so that one end of lamination 22 will overlap magnetic ribbon 49 and the opposite end will abut the edge of the turn of strip 48 being wound. It will be appreciated that an alternate leg lamination, e.g. 23, and an intermediate leg lamination, e.g. 22, will be assembled in each leg 12, 13, and 14 during each 360 degree rotation of mandrel 50. Different width leg laminations 17*a*, 17*b*, and 17*c* are inserted as the mandrel 50 is rotated in order to provide legs 12, 13 and 14 of cruciform cross section, and the arcuate cross section of the leg laminations 17 causes them to nest tightly and compactly together.

After the magnetic ribbons 48 and 49 have been wound to provide the desired number of laminations 17 in each leg 12, 13, and 14, the magnetic strips 48 and 49 may be severed and the ends secured to the turn radially inward therefrom by suitable means (not shown) such as rivets, tack welding, or brazing. The guide brackets 55 and 56 may then be removed. Studs 59 (see Fig. 5) similar to studs 52 may be screwed into threaded apertures 51 outward from the wound yoke members 10 and 11, and angle iron bars 60 having clearance holes (not shown) therethrough adapted to receive studs 52 and 59 may be assembled over the studs 52 and 59. Nuts 58 may then be threaded on the studs 52 and 59 to clamp the laminations 17 of legs 12, 13, and 14 and the wound turns of delta yoke members 10 and 11 firmly against the mandrel 50, and it will be apparent that the severed ends of strips 48 and 49 may, if desired, be inserted beneath one of the bars 60 to prevent unraveling of the wound turns.

Studs 64 may be screwed into the same apertures in which the bolts 57 for securing the brackets 55 and 56 were threaded, and angle iron bars 68 provided with clearance holes for receiving the studs 64 may be assembled over studs 64 and nuts 65 tightened on studs 64 to press against the wound turns of upper and lower loops 10 and 11 between the leg members 12, 13 and 14 to shape them to the desired approximately delta-shaped configuration. The magnetic core so held in desired shape is subjected to a suitable strain-relief anneal to restore the crystal lattice structure of the grains and to remove any deleterious strains introduced during the winding of upper and lower loops 10 and 11.

The turns of the upper and lower delta yoke members 10 and 11 assume a permanent set during annealing, and after annealing the turns of one of the yokes 10 or 11 may, if desired, be disassembled from the legs 12, 13 and 14. Preformed electrical coils 70 may then be inserted over the legs 12, 13 and 14, and the permanently set turns of the disassembled yoke member again interleaved with the leg laminations 17 of the legs 12, 13 and 14. However, in the preferred embodiment of the invention the delta yoke members 10 and 11 and leg laminations 17 are left in the same positions as that in which they were annealed, and electrical coils 70 are wound circumjacent the legs 12, 13 and 14, preferably by the well known method of forming a coil of copper on a preformed closed magnetic core of the type wherein the coil cannot be slipped over the core as disclosed in U.S. Patent 2,305,999 to A. G. Steinmayer et al. entitled "Method and Machine for Winding Coils" and having the same assignee as the subject invention.

If desired, suitable clamping means (not shown) may be inserted through the registering locating holes 26 and 27 in the leg laminations 17 of each of the leg members 12, 13 and 14 to hold the leg laminations compactly together.

It will be appreciated that the disclosed method of delta yoke core construction is considerably more efficient and economical of time and labor than the aforementioned prior art method wherein the upper yoke is held in suspended position above the three legs while the ends of the leg laminations are "picked" into place between turns of the upper yoke. A magnetic core constructed by reassembling permanently set laminations after the laminations have been threaded through the window of a preformed winding is always relatively "mushy" and the laminations never reassemble in as tight and compack relation as that in which they were annealed. It will be apparent that magnetic cores constructed in accordance with the invention are not disassembled and have exceptionally compact and tight interfitting of the

laminations. Further, the use of locating studs for accurately positioning the leg laminations during assembly, as well as guide brackets for accurately positioning the delta yoke turns during assembly, assures uniformity of the interleaving of yoke and leg laminations and provides remarkable consistency of magnetic characteristics between cores. This uniformity of electrical properties obviates the neecssity of providing extra iron to compensate for those cores on the low side of manufacturing tolerances and permits design of cores with a smaller amount of iron for a given kva. rating.

While only a single mode of practicing the invention has been illustrated and described, modifications and variations thereof will be apparent to those skilled in the art, and consequently it is intended in the appended claims to cover all such modifications and variations as fall within the true spirit and scope of the invention.

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

1. In the method of constructing a magnetic core having two parallel, spaced apart, spirally wound yoke members interconnected by a plurality of laminated, peripherally spaced apart, parallel leg portions, the steps of spirally flatwise winding two magnetic ribbons simultaneously at axially spaced apart positions on a rotatable mandrel to form said yoke members, concurrently with the winding step assembling straight leg laminations in radially aligned piles between the wound turns of said magnetic ribbons so that alternate leg laminations at opposite ends of each of said piles are interleaved with the turns of each of said yoke members, and strain-relief annealing said spirally wound yoke members with said leg laminations so interleaved.

2. In the method of constructing a delta yoke magnetic core having two parallel, spaced apart, spirally wound yoke members interconnected by each of three laminated, peripherally spaced apart, parallel leg portions, the steps of spirally flatwise winding two magnetic ribbons simultaneously at axially spaced apart positions on a rotatable mandrel to form said yoke members, concurrently with the winding step assembling straight leg laminations between turns of said magnetic ribbons and positioning said laminations in three radially aligned piles so that alternate laminations at opposite ends of each of said piles are interleaved with the wound turns of each of said yoke members, holding the wound turns with the leg laminations so interleaved, and strain-relief annealing the turns and laminations while so held.

3. In the method of constructing a delta yoke magnetic core having two parallel, spaced apart yoke members interconnected by each of three laminated, peripherally spaced apart, parallel leg portions, the steps of spirally flatwise winding two magnetic ribbons simultaneously at axially spaced apart positions on a rotatable mandrel to form said yoke members, concurrently with the winding step inserting three leg laminations between the turns of each of said magnetic ribbons during each 360 degrees of rotation of said mandrel, guiding said leg laminations to form radially aligned piles of laminations constituting said leg portions, the leg laminations being inserted so that alternate laminations at opposite ends of each of said piles are interleaved with the wound turns of each of said yoke members, holding the wound turns with the laminations so interleaved, and strain-relief annealing the turns and laminations while so held.

4. In the method of constructing a delta yoke magnetic core having two parallel, spaced apart yoke members interconnected by each of three laminated, peripherally spaced apart, parallel leg portions, the steps of spirally flatwise winding two magnetic ribbons simultaneously at axially spaced apart positions on a rotatable mandrel to form said yoke members, concurrently with the winding step inserting three leg laminations between the turns of each of said magnetic ribbons during each 360 degrees of rotation of said mandrel, guiding said leg laminations to form radially aligned piles of laminations constituting said leg portions, the leg laminations being inserted so that alternate laminations at opposite ends of each of said piles are interleaved with the wound turns of each of said yoke members, applying pressure against the yoke members at points between said piles in a direction radially inward toward said mandrel on which said yoke members are wound to shape said yoke members to desired configuration, holding the wound turns having the laminations so interleaved in said desired configuration, and strain-relief annealing the turns and laminations while so held.

5. In the method of constructing a delta yoke magnetic core having two parallel, spaced apart, yoke members interconnected by peripherally spaced apart, parallel, leg portions each having straight leg laminations provided with locating holes therethrough, the steps of forming yoke members by spirally flatwise winding two continuous strips of magnetic ribbon simultaneously at axially spaced apart positions on a rotatable mandrel concurrently with the winding step assembling said leg laminations between the turns of said strips with said locating holes in register whereby radially aligned piles of leg laminations constituting said leg portions are provided, the leg laminations being assembled so that alternate leg laminations at opposite ends of each of said piles are interleaved with the turns of each of said yoke members, holding the wound turns with the leg laminations so interleaved, and strain-relief annealing the turns and laminations while so held.

6. In the method of constructing a delta yoke magnetic core having two parallel, spaced apart, spirally wound yoke members interconnected by parallel leg portions, the steps of forming a plurality of equal length straight leg laminations having locating holes therethrough, forming two yoke members by spirally winding two continuous strips of magnetic ribbon simultaneously at axially spaced apart positions on a rotatable mandrel concurrently with the winding step assembling said leg laminations between the turns of said strips so that radially extending locating members project through said locating holes whereby radially aligned piles of said leg laminations constituting said leg portions are provided, the leg laminations being assembled with said turns so that alternate leg laminations at opposite ends of each of said piles are interleaved with the wound turns of each of said yoke members, and strain-relief annealing said spirally wound yoke members with said leg laminations so interleaved.

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