

Description

The present invention comes within the sector of the construction of inductive electrical appliances, especially of the static type, such as transformers.

5 More specifically, the invention relates to the production of the winding of the inductive coils equipping the abovementioned appliances and especially, but not exclusively, to the winding of the medium or high-voltage coils of transformers.

10 It is known that a customary practice for winding the coils of transformers involves winding one or more electrically conductive wires, generally made of copper, round and along a winding support according to a structure of the "solenoid" type with contiguous turns forming an annular layer. In general, this elementary operation
15 is repeated several times in succession in order finally to obtain a complete coil, the arrangement of which is in the form of a cylindrical reel composed of several concentric annular layers.

20 It is also known that, in addition to the initial sheathing of the copper wire with a film of insulating varnish, it is expedient, during winding, to interpose between the concentric layers separating sheets made of electrically insulating material, generally based on sheets of paper.

25 It will be recalled that these attached insulating sheets have essentially two functions: on the one hand, to prevent breakdowns between turns electrically distant from one another, but immediately next to one another in two adjacent layers, when the nominal working
30 voltage is applied at the input of the coil; on the other hand, above all, to ensure good stability during sudden surge voltages attributable, for example, to lightning strikes.

35 In this respect, the conventional simulation tests, called "shock-wave tests", which involve applying a voltage wave with steep fronts and of very short

duration and very high amplitude to the input of the transformer, are in some cases carried out at a contractual voltage more than five times higher than the nominal voltage of the transformer. In comparison, the tests of the breakdown threshold during normal operation are carried out at a voltage only double the nominal voltage.

It will be appreciated from this small amount of numerical information that the inter-layer insulation to be provided for withstanding the shock waves must go well beyond that which would be necessary when the appliance is under normal operating conditions and which could often be achieved merely by the packaging of the conductive wire.

It is known that these stresses arise because the coils have in relation to the voltage waves with steep fronts a capacitive predominance originating in a relatively complex network of capacitances in series and capacitances in parallel.

It has thus been possible to show that the latter result in an initial exponential distribution of the voltage along the coil, with a very pronounced voltage gradient on the first turns near the end of the coil receiving the shock wave.

It will therefore be seen how useful it would be to be able to take measures to prevent excessive insulation. To this end, the invention is aimed at obtaining a coil structure, in which the capacitances in parallel responsible for the concentrations of the abovementioned electrical stresses are reduced sufficiently to ensure a substantially uniform and linear damping of the voltage along the coil.

The coil structure according to the invention is of the type provided in the documents FR-E-26,143 or SU-A-173,283 which describe machines for winding a wire round and along a winding support into the form of stacked discs, each consisting of a spirally wound flat coil which develops radially alternately in the centrifugal direction and then in the centripetal direction when a change is made from one disc to the next.

The object of the invention is to provide a coil of the abovementioned type under conditions of industrial production.

To achieve this the subject of the invention is a process for winding inductive coils equipping electrical appliances, especially static appliances, such as transformers, and consisting of at least one electrically conductive wire wound round and along a winding support into the form of stacked discs, each consisting of a spirally wound flat coil which develops radially in the centrifugal direction and then in the centripetal direction when a change is made from one disc to the next, according to which process:

- the winding support is arranged vertically, and it is surrounded at a distance by a coaxial sleeve, to form between them an annular space for receiving the wire the bottom of which is closed off at least temporarily,

- the electrically conductive wire is introduced into the said space from the top, and the end of the wire is fastened in the bottom of the space, preferably to the winding support,

- then, in order to deposit the wire in the form of turns of desired diameter, the wire is conveyed continuously into the receiving space at a linear speed V (in m/s), whilst a relative rotational movement about the winding support at an angular speed W (in revolutions per second) is imparted to it, these two operations being carried out jointly, one of the two speeds being set at a reference value and the other variable speed being set in order to satisfy the following relation at any moment:

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d(a_i - 1))$$

where D represents the diameter of the winding support (in m) and d represents the diameter of the wire (in m) (see FR-E-26,143), characterized in that the conveyance of the wire and the relative movement about the winding support take place with the aid of two drive means independent of one another, in that the number of

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revolutions executed between the wire and the winding support is counted at any moment, in order to deduce from it the rank a_i of the turn being formed, a_i being a variable of integral value in that the said variable speed is determined by high-speed calculation means, and in that
5 the drive means on which the variable speed depends is actuated accordingly so that the said relation is satisfied at any moment.

According to a preferred embodiment, a relative rotational movement about the winding support is imparted
10 to the wire by causing the winding support to rotate about its axis.

According to another preferred alternative embodiment, the speed V of conveyance of the wire into the receiving space is kept constant, and the speed W_i of
15 the relative movement of winding of the wire round the winding support is regulated as a function of the rank of the turn being formed, according to the following relation:

$$20 \quad W_i = \frac{V}{\pi (D \times 2d (a_i - 1))}$$

Another subject of the invention is an apparatus for carrying out the process, in which a coiler comprises:

- a horizontal plate capable of being driven in
25 rotation at a variable speed about its vertical axis by means of a drive motor M_p , this plate being intended for receiving the winding support and the coaxial sleeve surrounding the latter at a distance, defining between them a space for receiving the wire,

30 - a unit for conveying the wire into the receiving space, located above the plate and having, on the one hand, a system for driving the wire and, on the other hand, a tube for guiding the wire from its exit from the said driving system, the said unit being movable in
35 a vertical translational motion (see FR-E-26,143), the said apparatus being characterized in that the wire is driven by means of a motor M_f separate from the motor M_p driving the plate, in that the wire guide tube is

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arranged substantially vertically in the receiving space,
in that the vertical translational motion of the wire
conveying unit takes place by means of a height-adjusting
motor Mg separate from the first two, and in that the
5 apparatus also possesses:

- a unit for controlling the motors of the coiler
comprising speed variators and a speed selector making
it possible to prepare a signal representing a reference
value to be imparted either to the motor Mf driving the
10 wire or to the motor Mp driving the plate,

- a control unit controlling the height-adjusting
motor Mg and the motor Mp or Mf not controlled by the
reference value, in order to satisfy the following rela-
tion at any moment:

15

$$\left(\frac{V}{W}\right)_i = \pi(D+2d(a_i - 1))$$

In this relation the same variables or parameters
represent the same quantities as in the relations given
previously.

As will doubtlessly already have been appreciated,
20 the invention is based on the well-known kinematic law
which links to one another the linear speed and the angu-
lar speed of a circular movement as a function of the
radius of the trajectory.

The invention makes use of this law by obtaining
25 synchronism between the speed of conveyance of the wire
and its speed of winding in turns, this synchronism
being set so as to impose a predetermined desired value
on the diameter of the turn being formed, by modulating
one of the speeds in relation to the other which is
30 kept fixed.

On the basis of that, this value is regulated in
time during winding, in order to obtain a coil arranged
in the form of a stack of discs, each consisting of a
spirally wound flat coil developing radially alternately
35 in the centrifugal direction and in the centripetal
direction when a change is made from one disc to the next.

This finally results in a coil structure having a

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minimum number of turns per layer, thus giving rise to a very low distributed capacitance of the electrical circuit and consequently a very extensive damping of the steep-front voltage pulses in the coil as a whole.

5 It must be emphasized that the coil structure obtained could not be exactly that of an ideal structure of clearly defined and individually distinct discs placed on one another, but comes very close to this.

10 On the other hand, the invention provides a winding method capable of meeting the particular criteria of the industrial production techniques, which is otherwise difficult to contemplate at least in the present state of knowledge, in order to obtain the ideally ordered winding structure mentioned above.

15 The results of tests conducted by the inventors show that, in actual fact, the desired stacking order is maintained at medium and long distance, by means of a certain mixing of the discs at a short distance, that is to say limited virtually to a few turns belonging
20 to adjacent discs.

 Despite this divergence from the ideal, the results and advantages which can be obtained from the invention both in technical terms and in industrial and economic terms are numerous and important. Mention may be made
25 for example, of the rise of the breakdown threshold during normal operations or a greatly improved resistance to the "shock-wave" tests, attributable to a capacitance distributed throughout the entire coil and of such quality that there is no need for inter-layer insulation.

30 Furthermore, concomitant advantages arise as the result of this, such as, in particular, the saving of raw material and labour, the lighter weight and less bulk of the finished appliance or the higher production speed because of the possibilities of complete or virtually
35 complete computer-assisted automation.

 The invention will be understood properly and other aspects and advantages will emerge more clearly from the following description given by way of example and with reference to the accompanying plates of drawings, in which:

- Figure 1 shows a general view of the most complete coiling apparatus which the inventors know how to make and which makes it possible to produce transformer coils. The coiler is shown in the foreground. The control and regulating accessories are illustrated symbolically in the right-hand part of the figure.

- Figure 2 is a block diagram showing the electrical circuit for controlling the coiling apparatus of Figure 1.

- Figures 3 and 4 are graphs showing respectively the curves of the winding speed and of the wire conveyance as a function of the number of turns deposited, according to two different operational versions.

The apparatus of Figure 1 is composed of a coiler 1 controlled by a programmable automatic mechanism 2 by means of a control unit 3.

Each of the abovementioned components will now be described.

The coiler comprises a stand 4, the upper plane part of which forms a work table 5. The latter has a horizontal plate 6 and supports an assembly 7 movable in vertical translational motion on two guide columns 8, 8' fastened in a double block 9.

The plate 6 is driven in rotation about its vertical axis 10 by means of a belt 11 actuated by a pinion 12 and forming a gearing-down unit actuated by a variable speed motor (Mp) 13 retracted into the stand.

As can be seen, a cylindrical body 14 forming the winding support is placed vertically on the plate 6 being centred on the axis of rotation 10.

According to the invention the winding support 14 is surrounded at a distance by a coaxial sleeve 15 defining between them an annular space 16 intended for receiving the coil.

This space is closed at its base by means of the surface of the plate 6, and its upper end is left open for introducing the electrical wire to be wound.

The movable assembly 7 forms a unit for conveying this electrical wire, seen at 17, into the winding space 16 from a conventional unreeling device which is

not shown so as not to overload the figure needlessly. This assembly is shaped as a housing without lateral faces. The front face 41 has two identical pairs of rollers 19, 19' arranged one above the other and, by means of two guide belts 20, 20' driving the wire 17 from the top downwards in the direction indicated by the arrow. The rear vertical face 21 of the housing is equipped with two bushes 22, 22' sliding on the columns 8, 8' and with an internally threaded collar (not shown) engaged in a vertical endless screw 23. This screw is actuated by a motor (Mg) 24 ensuring the adjustment of the height of the movable assembly 7 and mounted on a platform 25 fastened to the end of the columns 8, 8'.

The rollers 19, 19' are actuated in rotation by a variable-speed motor (Mf) 26 fastened to the rear of a supporting flange 27 located between the front and rear faces 41, 21 of the assembly 7.

For this purpose, the front face of the flange carries the members for the gearing-down transmission of movement, which, as can be seen, comprise a belt 28 connecting a small driving pinion 29 to a driven pinion 30 which, by means of a set of gears (not shown) actuates the upper rollers of 19 which in turn drive the lower rollers by means of the belts 20 and 20'.

The flange 27 is attached to the front face 41 at a distance by means of fastening struts 31. Furthermore, the front face 41 is itself held between two upper and lower horizontal panels 32 and 33 respectively, produced by bending the rear face 21.

As can be seen, each panel 32, 33 at its front end has a substantially vertical tube 34, 35 respectively, for guiding the electrically conductive wire 17.

The guide tube 34 of the upper panel forms a means for receiving the wire from the unreeling device (not shown) and, at its lower orifice, delivers it to the inlet of the set of drive rollers 19, 19' between the inner strands of the transport belts 20, 20'.

The guide tube 35 is centred on the outlet of

the set of rollers, from which it receives the wire 17 at its upper open end and delivers it at its lower end. The latter opens into the receiving space 16, giving the wire a tangential path preformed into a turn by means of its end part 36 bent horizontally in the direction of rotation of the plate 6 and turned in in the direction of the axis 10 of the plate, matching the curvature of the space 16. As can be see, this end part 36 has a double "S"-shaped curvature, the form and function of which will be explained specifically at the end.

This assembly is completed by three revolution counters 37, 38 and 39, each equipping a motor, and an incremental coder 40 mounted at the end of the shaft of the motor (Mf) 26 for driving the wire.

Finally, an electrical connection box, symbolized at 58 on the flank of the stand 4, connects the coiler to its accessories which are the control unit 3 and the programmable automatic mechanism 2 controlling the apparatus as a whole.

Shown diagrammatically on the latter are the keyboard 42 for entering the operating parameters of the coiler and, at 43, the screens displaying the operating characteristics. This automatic mechanism has been programmed to allow it to control the operation of the coiler according to the process of the invention, as described below.

The control unit 3 comprises three subassemblies 44, 45 and 46 which represent electronic speed variators controlling the running of the motors of the coiler.

As can be seen in detail in Figure 2 these variators each consist of a regulating loop comprising a comparator 47, 48, 49, of which the output is connected to the motor and of which one input is connected to the revolution counter of the motor in question and the other input receives a reference value representing the speed to be applied to the said motor. In the example as illustrated, the respective reference values of the motors (Mp) 13 and (Mg) 24 are prepared by the programmable automatic mechanism 2 after the signals have been shaped in digital

analogue convertors 50, 51, whereas for the motor (Mf) 26 driving the wire the reference value is supplied by a manual speed selector 52.

This selector is a contact potentiometer making it possible to set the speed of the motor to a preselected reference value.

Furthermore, the automatic mechanism 2 receives, at these "control process" inputs, on the one hand a signal (F) representing the speed of the wire-driving motor (Mf) 26 supplied by the incremental coder 40, and on the other hand two signals (P) and (H) representing at each moment the number of revolutions executed respectively by the motor (Mp) 13 driving the plate 6 and the motor (Mg) 24 for adjusting the height of the movable assembly 7, these two signals being supplied by integrators 53 and 54.

It is clear that the quantities (P) and (H) are directly linked respectively to the number of revolutions executed by the plate (therefore to the number of turns deposited) and to the height of the end (36) of the guide tube (35) (therefore the number of discs formed) and which the automatic mechanism 2 will be capable of calculating.

The same is true, moreover, of the signal (F) supplied by the coder 40 as data for calculating the instantaneous wire-conveying speed designated by V in Figure 1.

Now that these particulars have been given, it will be possible to describe the operation of the apparatus according to the process of the invention.

The preliminary operation involves centring the winding support 14 on the rotary plate 6 and anchoring the wire 17 at its free end to the base of this support by any suitable means, for example by means of a simple slit made in the support 14.

The coaxial sleeve 15 is then placed round the support 14 as shown in Figure 1, in order to confine laterally the space 16 for receiving the coil to be produced. The movable assembly 7 is then centred laterally in order to place the guide tube 35 half-way between the support 14 and the sleeve 15, and the movable assembly 7 is put in the low position so that the bent end 36 of

the guide tube 35 opens out near the anchoring point of the wire 17.

This operation, although not indispensable, is nevertheless recommended, because it ensures a better control of the depositing of the turns by limiting the free travel of the wire 17 at the exit of the tube 35. Finally, the wire 17 is tensioned by a slight pull upstream of the feed tube 34, and the coiler is then ready for operation.

To carry out winding by the method according to the invention, the operator enters the operating constants in the automatic mechanism 2 by means of the keyboard 42 on the front of the latter.

In this particular case, these constants are the diameter d of the wire 17, the outside diameter D of the winding support 14, the inside diameter " Φ " of the sleeve 15, the diameter " g " of the drive rollers 19, 19', the total number G of discs to be formed, and the speed V of conveyance of the wire 17 into the receiving space 16.

By means of these data, the program stored by the automatic mechanism 2 calculates, on the one hand, the number n of turns per disc (that is to say

$$n = \frac{\Phi - D}{2d})$$

and, on the other hand, the rotational speed " η " to be given to the motor (Mf) 26 for driving the rollers 19, 19' (that is to say $\eta = f(V, g)$, where f is a function which represents the kinematic characteristics of the transmission train 28, 29, 30 and which can be converted into wired logic within the automatic mechanism).

The results obtained are stored in the working memory and the program then prepares a speed function W representing the instantaneous rotational speed to be imparted to the plate 6 and therefore also the speed of winding of the wire in the space 16.

This function, which allows the automatic mechanism 2 to control the winding process in real time, is written:

$$W_i = \frac{V}{\pi (D + 2d(a_i - 1))}$$

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It is pointed out once again here that a_i is a variable of integral value indicating the desired rank of the i 'th turn in the disk being formed in the receiving space 16, counting from the winding support 14, the increment i thus going from 1 to n and vice versa.

The values assumed by the discrete variable a_i are obtained continuously by the remainder (r) of the division between the values of the signal (P) and the signal (H), either directly if (H) is odd or by the complement to n , if (H) is even.

It will be appreciated that these arrangements arise because, with the end of the wire 17 anchored on the winding support 14, the first disc which forms is a spiral developing radially in a centrifugal manner, the second then being a spiral developing radially in a centripetal manner, and so on and so forth. Of course, the parities would be reversed if the wire were anchored to the sleeve 15.

To start the actual winding operation, it is sufficient to mark up by means of the manual potentiometer 52 a reference value (R) determining the speed V of conveyance of the wire 17.

During the entire starting phase, a ramp function is prepared at the reference value so that the system progressively assumes a steady state.

It should be noted that, during this entire initial transient phase, the speed V of conveyance of the wire is a variable which the automatic mechanism 2 calculates from a reading of the signal (F) received by the incremental coder 40 equipping the motor (M_f) 26.

Of course, in a steady state, (R) and (F) are equal, to the nearest degree of accuracy of the measuring instruments and the stability characteristics of the coiler.

In a steady state, the wire 17 introduced into the space 16 by the guide tube 35 at a constant speed V imparted by the set of rollers 19, 19' is deposited in this space in the form of turns 18, giving it its winding movement about the support 14 under the effect of the

rotation W of the plate 6 in the direction indicated by the arrow.

It should be noted that the formation of the turn is also assisted by the central position of the guide tube 35 in terms of the width of the space 16 and by its bent end 36 which makes it possible to inject the wire along a path preformed into a turn of medium diameter.

Subjecting W to a set by the automatic mechanism 2 as a function of V, according to the relation given above, ensures the control of the diameter of the turn being formed and thereby makes it possible to coil a first disc spirally wound from the inside and then, when the number n of turns is reached, a second disc this time spirally wound from the periphery and placed on the preceding one, and so on and so forth until the maximum number G of discs allowed is obtained. In general, the data G is determined as a function of the diameter "d" of the wire, in order to fill the receiving space 16 to approximately 4/5ths of its volume.

Whenever a disc has been coiled, the automatic mechanism 2, by means of the speed variator 44 (Fig.1), commands the motor (Mg) 24 to raise the wire-conveying unit 7 by a height equal to the diameter of the wire. In view of what was said above, it is possible to take the precaution of providing, at a suitable location on the guide columns 8, 8', a limit stop which stops the entire operation when the desired degree of filling of the receiving space 16 is reached. This arrangement makes it possible, if appropriate, to overcome the consequences of entering in the automatic mechanism a value of G incorrect by excess.

It is expedient to emphasise that one of the decisive aspects of the invention is that the wire 17 is not pulled by the rotating winding support 14, but pushed by the feed system 7, the said push interacting with the winding action, so as to result, in the region of the turn being formed, in a radial force of which the centrifugal or centripetal direction and the intensity depend on the degree of advance of the coil. This force gives

the said turn the desired diameter appropriate to the location, that is to say the rank assigned to it within the spirally wound flat disc being formed.

Such are the essential and fundamental means of the invention, expressed differently from before, but in an equivalent way.

This being so, a cyclic pulsation of the wire-winding speed W in time is therefore generated, and, as shown clearly in Figure 3, its period corresponds to the formation time of two consecutive discs, that is to say to $2n$ revolutions of the plate 6.

This figure illustrates an example of winding according to the invention comprising six turns per disk.

On the abscissa are placed successively from the upper reference mark the total number N_t of turns of the coil, the rank a_i of each turn in its disc and the number of disks in a coil.

As can be seen, the average course of the curve representing W against the period shown is that of two symmetrical hyperbolic segments placed end to end; the first segment of decreasing slope corresponds to the ("centrifugal" formation of the) first disc, and the following segment of increasing slope represents the "centripetal" formation of the second disc.

A closer examination shows that the curve is formed from successive steps with variable height off-sets, embodying the discrete variations in the rotational speed of the plate occurring during the change from one turn to the next in the same disc.

It will be appreciated, in this respect, that the most efficient possible implementation of the invention presupposes a very accurate regulation of the winding speed, making it necessary to resort to numerical control techniques which the programmable automatic mechanism 2 specifically allows.

Comparative tests were carried out on a coil according to the invention, produced with a round copper wire

of a diameter of 1.12 mm , wound into 175 discs at the rate of 20 turns per disc, corresponding to a transformer of class 24.

5 The tests showed a very high resistance of the coil to voltage shocks simulating lightning strikes, this being achieved without any insulation other than the original packaging of the copper wire in a conventional sheath of baked enamel.

10 As an indication, whereas the contractual stipulations for the shock resistance of transformers of the abovementioned class are of the order of 125 kV, the test coil according to the invention easily withstands voltage pulses going beyond 200 kV.

15 In general terms it becomes clear that the invention makes it possible to exceed by far the present characteristics of transformers.

As already emphasized, it allows the industrial production of transformers without any attached insulation, ensuring a saving of material and labour and a substantial reduction in the weight and bulk of the finished appliance. It goes without saying that the invention need not be limited to the example described above but embraces many alternative versions and equivalents, in as much as the characteristics set out in the accompanying claims are satisfied.

25 In this respect, it is important to bear in mind that the invention, in its most general meaning, puts into effect two separate operations having kinematics of a relative nature: the winding of the turns on the one hand, and the link between the speed of the said winding and the speed of conveyance of the wire, on the other hand.

30 In fact, the winding of the turns can be carried out not only as the result of the rotation of the winding support, the point of conveyance of the wire being fixed in space, but also, in an equivalent way, by keeping the winding support stationary and by rotating the wire round it. This can be carried out for example, by means of a wire-conveying unit such as 7, which is designed as a pivoting turret centred above the plate.

Likewise, the link to be made between the speed of winding of the turns and the speed of conveyance of the wire, as a function of the development of the disc being formed, can be obtained not only by modulating speed W , with the conveying speed V being kept constant, but also, in an equivalent way, by fixing the winding speed at a specific reference value and by regulating the speed of conveyance of the wire.

In this case the kinematic relation which links these two speeds and which must be taken into account by the automatic mechanism 2 is written:

$$V_i = \pi (D + 2d(a_i - 1)) \cdot W$$

in which the parameters continue to have the definition given previously.

It will therefore be appreciated that, in its most general formulation, the relation to be satisfied according to the invention is consequently expressed in the following form:

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d(a_i - 1))$$

As an indication, Figure 4 similar to Figure 3, shows the course of the curve representing the variations to be imparted to the speed V of conveyance of the wire, when the speed W of winding of the turns is kept constant.

As can be seen, in the period of formation of two discs, this curve has on average the form of two straight segments symmetrical relative to one another, which meet at their high point corresponding to the change from the first disk to the second and of which the slope has, in terms of absolute value, $\text{tg}\beta = 2d \cdot W$.

It will be seen, moreover, that each segment consists, in fact, of a succession of steps connected by means of equal vertical portions, corresponding to the speed increment of $2dW$ to be added to (or subtracted from) the speed of conveyance of the wire when a change is made

from one turn to the next on the same disc.

It must be emphasized that the apparatus described above possesses means allowing it to operate either at a constant speed V of conveyance of the wire or at a constant speed W of winding of the turns.

These means, symbolized in Figure 2, consist of a two-positioned selector 55 making it possible to connect the incremental coder 40 to one or other of the motors (Mf) 26 or (Mp) 13, and of a reversing switch 56, of which the transfer to the left in relation to its position shown in Figure 2 makes it possible to apply the speed reference (R) to the input of the comparator 48 of the motor (Mp) 13 and connect the comparator 47 of the motor (Mf) 26 to the convertor 50.

A general changeover switch 57 is provided on the automatic mechanism 2 making it possible to control these means at the same time as the change from one operating programme to another according to the choice of speed V or W which is kept constant.

It is expedient to point out that the possibility of adjusting the height of the conveying unit 7 need not necessarily be an indispensable characteristic of the invention. However, as already mentioned, its usefulness is that the wire is fed into the receiving space in the vicinity, in height terms, of the place of deposit of the turns, thus contributing, because the lag between the moment of the formation of the turn and its depositing within the disc being formed is minimized, to improving the order of the ranking of the turns in the particular structure of the desired coil.

It may be mentioned, in this respect, that the abovementioned ranking order is assessed quantitatively by means of a so-called coefficient of "growth" of the turns in the finished coil. In fact, tests have shown that this coefficient which, in the sector in question, is defined as the ratio between the volume of the receiving space and the volume occupied by the turns constitutes, where the invention is concerned, an indicator of the divergence of the produced coil from the ideal, in which

as will be recalled, there would be no mixing turns between consecutive discs.

Another arrangement, not indispensable, but also making it possible to minimize the coefficient of growth is found in the turned-in and bent form of the end part 36 of the guide tube 35 for conveying the wire. This arrangement ensures a substantially tangential introduction of the wire into the receiving space and consequently makes it possible to preform the wire into a turn which is inscribed within the annular space 16. Furthermore, locating the guide tube 35 half-way between the winding support and the outer sleeve makes it possible to give this turn a mean diameter, thus also tending to improve the quality of the ranking of the turns.

It will easily be appreciated that these arrangements combine their effect in a very favourable way with that of an adjustment of the height of the point of introduction of the wire into the receiving space, that is to say, with reference to the apparatus described, the adjustment of the height of the conveying unit 7.

Another alternative embodiment making it possible to come even closer to the ideal coil structure involves providing a mechanism for the lateral movement of the tube 35 (if appropriate, of the movable wire-conveying assembly 7), in order to subject the position of its outlet end to the diameter of the turn being formed, so as to feed the wire into the receiving space at a point located in line with the place of deposit of each turn.

It is useful to mention that a highly advantageous feature of the invention, which will be greatly appreciated by the builders of transformers, involves choosing as the winding support the low-voltage column of the appliance to be produced.

Furthermore, the sleeve 15 serving for delimiting the contour of the coil can advantageously be a cardboard shell which is placed permanently in position and which will likewise serve subsequently for insulating the coil relative to the frame of the tank of final intended use.

An especially expedient aspect of the invention is, therefore, that it makes it possible to use directly a complete transformer element which can be placed on its magnetic core, without preparation or modification of any kind, except, where appropriate, for the fitting of the conventional clamping discs on the ends of the coil, while one of them can advantageously be provided initially at the base of the receiving space during the installation of the winding support and sleeve on the plate of the coiler.

It must also be stressed that the invention is entirely compatible with the installation of a coil-cooling system, if desired. This does not present any problem which has not been mastered, because it is easy to insert cooling channels between the discs by introducing perforated plates during winding as the result of momentary stops of the coiler.

Moreover, experience has shown that, with a guide tube 35 simply bent at its outlet end, the turns being formed tend to lift up at high rotational speeds of the plate.

To remedy this, as shown in Figure 1, the inventors have shaped the end part 36 of the guide tube into a horizontal "S" that is to say in a double curve. Since the second curve is opposite the first, the outlet orifice is therefore directed downwards, thus making it possible to turn the wire down towards the bed of turns already deposited, and in this way the abovementioned difficulties disappear even at high rotational speeds.

The invention can be put into practice with wires of the smallest diameter up to values higher than 10 mm.

Of course, for large diameters, it is desirable to use flexible copper wires suitably annealed for this purpose.

The coils can be produced without difficulty at high speed (that is to say, several hundred revolutions per minute), each wire diameter of course having its ideal winding speed or winding-speed range which a person skilled in the art will be able to determine quickly if he wishes to put the invention into practice under the

best possible productivity conditions. Purely as an indication, a copper wire of a diameter of 0.9 mm is perfectly suitable for top rotational speeds of the plate of approximately 400 revolutions per minute.

5 The invention applies preferably, but in a non-limiting way, to the high and medium-voltage coils of transformers.

10 The invention, although designed initially for transformers, is not thereby limited to this use, but extends to the production of electrical coils intended for any inductive appliance, especially of the static type, having a large number of turns conventionally organized in long concentric layers.

15 Likewise, the invention can make use of electrically conductive wires to be coiled of different shapes (round, square, rectangular) and of different sizes.

20 In the same way too the invention covers the execution of the winding of coils both with a single wire and with multiple wires. Finally, also, the operator remains free as to the choice of the operating parameters of the coiling apparatus, especially as to the choice of the reference speed which he can pre-determine according to his wishes or needs.

Claims

1. Process for winding inductive coils equipping electrical appliances, especially static appliances, such as transformers, and consisting of at least one electrically conductive wire (17) wound round and along a winding support (14) into the form of stacked discs each consisting of a spirally wound flat coil which develops radially alternately in the centrifugal direction and then in the centripetal direction when a change is made from one disc to the next, according to which process :
- the winding support (14) is arranged vertically, and it is surrounded at a distance by a coaxial sleeve (15) to form between them an annular space (16) for receiving the wire (17) and the bottom of which is closed off temporarily,
 - the wire (17) is introduced into the space (16) from the top, and the end of the wire is fastened to the base of the said space, preferably to the winding support (14),
 - and, for the purpose of depositing the wire (17) in the form of turns (18) of desired diameter, the wire is conveyed continuously into the receiving space (16) at a linear speed V , whilst a relative rotational movement about the winding support at an angular speed W is imparted to it, these two operations being carried out jointly, one of the two speeds being set at a reference value and the other variable speed being set so as to satisfy the following relation:

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d (a_i - 1))$$

where V is expressed in metres per second, W is expressed in revolutions per second and a_i is counted from the winding support, and where D represents the diameter of the winding support expressed in metres and d represents the diameter of the wire expressed in metres; the said process being characterized in that the conveyance of



the wire and the relative rotational movement about the winding support take place with the aid of two drive means (26, 13) independent of one another, in that the number of rotations executed between the wire and the winding support is counted at any moment in order to deduce from it the rank a_i of the turn being formed, a_i being a variable of integral value, in that the said variable speed is determined by high-speed calculation means, and in that the drive means on which the variable speed depends is actuated accordingly, so that the said relation is satisfied at any moment.

2. Process according to Claim 1, characterized in that a relative rotational movement about the winding support (14) is imparted to the wire (17) by causing the winding support to rotate about its axis.

3. Process according to Claim 1 or 2, characterized in that the speed V of conveyance of the wire (17) into the receiving space (16) is kept constant, and the relative rotational speed W_i of the wire round the winding support (14) is regulated as a function of the rank a_i of the turn being formed, by means of the relation:

$$W_i = \frac{V}{\pi (D \times 2d (a_i - 1))}$$

where D and d expressed in m , represent respectively the diameter of the winding support (14) and the diameter of the wire (17).

4. Process according to Claim 1 or 2, characterized in that the wire (17) is conveyed into the receiving space (16) along a path which terminates horizontally.

5. Process according to Claims 1, 2 or 4, characterized in that the wire (17) is conveyed into the receiving space (16) by introducing it therein at a height level regulated as a function of the height level of the depositing of the turn (18).

6. Process according to Claims 1, 2, 4 or 5, characterized in that the wire (17) is conveyed into the receiving space (16) in a radial position located half-way between the winding support (14) and the coaxial



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sleeve (15).

7. Process according to Claims 1, 2, 4 or 5, characterized in that the wire (17) is conveyed into the receiving space (16) between the winding support (14) and the coaxial sleeve (15), in a radial position in line with the place of deposit of each turn (18).

8. Apparatus for carrying out the process according to Claim 1, in which a coiler (1) comprises:

- a horizontal plate (6) which can be rotated at a variable speed about its vertical axis (10) by means of a drive motor Mp (13), this plate being intended for receiving the support (14) for winding the electrically conductive wire (17) and the coaxial sleeve (15) surrounding the support (14) at a distance, defining between them a space (16) for receiving the wire;

- a unit (7) for conveying the wire into the space (16), located above the plate (6) and having, on the one hand, a system (19, 19', 20, 20') for driving the wire and on the other hand, a tube (35) for guiding the wire (17) from its exit from the said driving system, the said unit (7) being movable in vertical translational motion; the said apparatus being characterized in that the wire (17) is driven by a motor Mf (26) separate from the motor Mp (13) driving the plate, in that the wire guide tube (35) is arranged substantially vertically in the receiving space (16), in that the vertical translational motion of the said wire-conveying unit (7) takes place by means of a height-adjusting motor Mg (24) separate from the first two, and in that the apparatus also possesses:

- a unit (3) for controlling the motors (13, 24, 26), comprising speed variators (44, 45, 46) and a speed selector (52) making it possible to prepare a signal (R) representing a reference speed to be imparted either to the motor Mf (26) driving the wire (17) or to the motor Mp (13) driving the plate;

- and a control unit (2) controlling the height-adjusting motor Mg (24) and the motor Mp (13) or Mf (26) not controlled by the reference value (R), so as to satisfy the following relation:



* C L N S *

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d (a_i - 1))$$

where V represents the speed of driving of the wire (17) into the receiving space (16) (in m/s). W represents the rotational speed of the plate (6) (in revolutions per second), D and d represent respectively the diameter of the winding support (14) and the diameter of the wire (17) (in m) and a_i represents the rank of the i 'th turn being formed in the receiving space (16) between the winding support (14) and the coaxial outer sleeve (15), counting from the said support.

9. Apparatus according to Claim 8, characterized in that the tube (35) has an end outlet part (36) bent in in a double "S"-shaped curve, the outward orifice of which is directed downwards.

10. Apparatus according to Claims 8 or 9, characterized in that the wire guide tube (35) is movable in horizontal translational motion.

11. Apparatus according to Claim 8, characterized in that the control unit consists of a programmable automatic mechanism (2) which, at its input, receives signals (F), (H), (P) representing the operating characteristics of the apparatus and prepared by speed sensors (37, 38, 39, 40) equipping the motors (13, 24, 26).



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As printed.

Claims

1. A method for winding inductive coils with which electrical devices, in particular static devices such as transformers, are equipped, said coils comprising at least one electrically conductive wire (17) wound around and along a winding support (14) of laminated disk coils each consisting of a flat spirally wound coil which uncoils radially alternately in the centrifugal direction and then in the centripetal direction when one passes from one disk coil to the next, said method comprising the following steps:

- the winding support (14) is disposed vertically and surrounded at a distance by a coaxial sheath (15) so as to create an annular space (16) therebetween for receiving the wire (17) and whose bottom is temporarily closed off,
- the wire (17) is introduced into the space (16) from above and the end of the wire is fixed to the base of said space, preferably on the winding support (14),
- and, in order to dispose the wire (17) in the form of turns (18) of a desired diameter, the wire is continuously fed into the receiving space (16) at a linear speed V while being imparted a relative movement of rotation about the winding support at an angular speed W, these two operations being effected jointly, one of the two speeds being regulated to a desired value and the other, being variable, being regulated so as to respect the following relation:

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d (a_i - 1))$$

wherein V is expressed in meters per second, W is expressed in revolutions per second and a_i is counted starting from the winding support, wherein D represents the diameter of the winding support expressed in meters and d represents the diameter of the wire expressed in meters; said method being characterized in that the feeding of the wire and the relative movement of rotation about the winding support are effected by aid of two mutually independent motive means (26, 13), in that the number of rotations realized between the wire and the winding support is counted at all times in order to deduce the rank a_i of the turn being formed, a_i being a variable with an integral value; in that said variable speed is determined by aid of fast calculating means, and in that the motive means on which the variable speed depends is consequently activated in order that said relation be respected at all times.

2. The method according to claim 1, characterized in that the wire (17) is imparted a relative movement of rotation about the winding support (14) by having the latter rotate about its axis.

3. The method according to claim 1 or 2, characterized in that the speed V at which the wire (17) is fed into the receiving space (16) is kept constant and the speed W_i of relative rotation of the wire about the winding support (14) is regulated as a function of the rank a_i of the turn being formed by aid of the relation:

$$W_i = \frac{V}{\pi (D + 2d (a_i - 1))}$$

wherein D and d represent, expressed in meters, the diameter of the winding support (14) and the diameter of the wire (17), respectively.

4. The method according to claim 1 or 2, characterized in that the wire (17) is fed into the receiving space (16) in accordance with a trajectory which ends horizontally.

5. The method according to claims 1, 2 or 4, characterized in that the wire (17) is fed into the receiving space (16) by being introduced at a regulated level of height as a function of the level of height of the depositing of the turn (18).

6. The method according to claims 1, 2, 4 or 5, characterized in that the wire (17) is fed into the receiving space (16) in a radial position situated half-way between the winding support (14) and the coaxial sheath (15).

7. The method according to claims 1, 2, 4 or 5, characterized in that the wire (17) is fed into the receiving space (16) between the winding support (14) and the coaxial sheath (15) in a radial position perpendicular to the place where each turn (18) is deposited.

8. An apparatus for carrying out the method according to claim 1, in which a coiler comprises:

- a horizontal plate (6) capable of being rotated at a variable speed about its vertical axis (10) by a driving motor M (13), said plate being intended to receive the winding support (14) for the electrically conductive wire (17) and the coaxial sheath (15) surrounding the support (14) at a distance defining a space (16) for receiving the wire therebetween;





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- a unit (7) for feeding the wire into the space (16) placed above the plate (6) and comprising on one side a system (19, 19', 20, 20') for pulling-along the wire and on the other side a tube (35) for guiding the wire (17) from its exit out of said pulling along system, said unit (7) being mobile by vertical displacement; said apparatus being characterized in that the wire (17) is pulled along by a motor Mf (26) distinct from the motor Mp (13) driving the plate, in that the tube (35) for guiding the wire is disposed substantially vertically in the receiving space (16), in that the vertical displacement of said unit (6) for feeding the wire is effected by a height regulating motor Mg (24) distinct from the first two motors, and in that the apparatus further comprises:
 - a unit (3) for controlling the motors (13, 24, 26) comprising variable speed drives (44, 45, 46) and a speed selector (52) allowing for a signal (R) representing a desired speed to be processed for imparting said speed either to the motor Mf (26) for pulling along the wire (17) or to the motor Mp (13) for driving the plate;
 - and a control unit (2) for controlling the height regulating motor Mg (24) and the motor Mp (13) or Mf (26) not activated by the desired value (R) in such a way as to respect the following relation:

$$\left(\frac{V}{W}\right)_1 = \pi (D + 2d (a_i - 1))$$

wherein V represents the speed at which the wire (17) is fed into the receiving space (16) (in m/s), W represents the rotational speed of the plate (6) (in rps), D and d represent the diameter of the winding support (14) and the diameter of the wire (17), respectively (in m), and a_i represents the rank of the i-th turn being formed in the receiving space (16) between the winding support (14) and the outer coaxial sheath (15), and counted starting from said support.

9. The apparatus according to claim 8, characterized in that the tube (35) comprises an end outlet portion (36) folded over according to a double curve in an S shape, whose outlet opening is directed downwardly.
10. The apparatus according to claims 8 or 9, characterized in that the tube (35) for guiding the wire is mobile by horizontal displacement.
11. The apparatus according to claim 8, characterized in that the control unit comprises a programmable automaton (2) which receives as input signals (F), (H), (P) representing operating characteristics of the apparatus and processed by speed sensors (37, 38, 39, 40) with which the motors (13, 24, 26) are equipped.

Patentansprüche

1. Verfahren zum Wickeln von induktiven Spulen, mit denen elektrische Geräte, insbesondere statische Geräte wie Transformatoren, ausgerüstet sind und die aus mindestens einem elektrisch leitenden Draht (17) bestehen, der entlang eines Spulenhalters (14) und um diesen herum in Form aufeinandergestapelter Flachspulen gewickelt ist, deren jede aus einer spiralförmigen flachen Spule besteht, die sich radial abwechselnd in Zentrifugalrichtung und in Zentripetalrichtung erstrecken, beim Übergang von einer Flachspule zur nächsten, bei dem:

- der Spulenhalter (14) vertikal angeordnet wird und im Abstand von einer coaxialen Hülle (15) derart umgeben wird, daß zwischen ihnen ein ringförmiger Raum (16) zur Aufnahme des Drahtes (17) entsteht, wobei sein Boden zeitweise verschlossen wird,
- der Draht (17) in den Raum (16) von oben eingebracht wird und das Drahtende am Boden dieses Raumes befestigt wird, vorzugsweise am Spulenhalter (14) und
- um den Draht (17) in Windungen (18) mit gewolltem Durchmesser einzubringen, der Draht kontinuierlich in den Aufnahmeaum (16) mit einer linearen Geschwindigkeit V eingeführt wird, wobei ihm eine relative Drehbewegung um den Spulenhalter mit einer Winkelgeschwindigkeit W erteilt wird und wobei diese beiden Schritte gleichzeitig durchgeführt werden, unter Steuerung einer der beiden Geschwindigkeiten durch einen Sollwert und der anderen, variablen, derart, daß die folgende Beziehung erfüllt wird:

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d (a_i - 1))$$

in der V in Metern pro Sekunde dargestellt ist, W in Umdrehungen pro Sekunde, a_i ausgehend vom Spulenhalter gezählt wird, D den Durchmesser des Spulenhalters in Metern darstellt und d den Durchmesser des Drahtes in Metern darstellt, dadurch gekennzeichnet, daß die Drahtzufuhr und die relative Drehbewegung um den Spulenhalter mittels zweier voneinander unabhängiger Motoranordnungen (26, 13) erfolgen, daß zu jedem Zeitpunkt die Anzahl der Umdrehungen zwischen dem Draht und dem Spulenhalter gezählt wird, um daraus die Schicht a_i der sich bildenden Windung abzuleiten, wobei a_i eine ganzzahlige Variable ist, daß mittels einer Schnellrechneranordnung die variable Geschwindigkeit ermittelt wird und daß daraufhin die Motoranordnung, von der die variable Geschwindigkeit abhängt, betätigt wird, so daß die genannte Beziehung jederzeit eingehalten wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß dem Draht (17) die relative Drehbewegung um den Spulenhalter (14) herum dadurch erteilt wird, daß letzterer um seine Achse gedreht wird.

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3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die Geschwindigkeit V der Zufuhr des Drahtes (17) in den Aufnahmeraum (16) konstant gehalten wird und daß die Geschwindigkeit W_i der Relativdrehung des Drahtes um den Spulenhalter (14) als Funktion der Schicht a_i der gebildeten Windung gesteuert wird mittels der Beziehung

$$W_i = \frac{V}{\pi (D + 2d (a_i - 1))}$$

in der D und d in Metern den Durchmesser des Spulenhalters (14) bzw. den Durchmesser des Drahtes (17) darstellen.

4. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß der Draht (17) in den Aufnahmeraum (16) entlang eines Weges eingeführt wird, der waagrecht endet.

5. Verfahren nach Ansprüchen 1, 2 oder 4, dadurch gekennzeichnet, daß der Draht (17) dem Aufnahmeraum (16) derart zugeführt wird, daß er auf einem Niveau eingebracht wird, dessen Höhe als Funktion der Höhe des Ausbildens der Windung (18) gesteuert wird.

6. Verfahren nach Ansprüchen 1, 2, 4 oder 5, dadurch gekennzeichnet, daß der Draht (17) dem Aufnahmeraum (16) an einer radialen Stelle zugeführt wird, die sich auf halbem Wege zwischen dem Spulenhalter (14) und der coaxialen Hülle (15) befindet.

7. Verfahren nach Ansprüchen 1, 2, 4 oder 5, dadurch gekennzeichnet, daß der Draht (17) dem Aufnahmeraum (16) zwischen dem Spulenhalter (14) und der coaxialen Hülle (15) an einer radialen Stelle senkrecht zur Anordnungsrichtung einer jeden Windung (18) zugeführt wird.

8. Vorrichtung zur Durchführung des Verfahrens nach Anspruch 1, mit einer Wickelmaschine (1) die folgende Teile aufweist:

- eine waagrechte Platte (6), die mit variabler Geschwindigkeit in Drehungen versetzt werden kann um ihre senkrechte Achse (10) mittels eines Antriebsmotors M_p (13), wobei die Platte (13) dazu dient, den Spulenhalter (14) für den elektrisch leitenden Draht (17) aufzunehmen sowie eine coaxiale Hülle (15), die den Kern (14) im Abstand umgibt, so daß ein Aufnahmeraum (16) für den Draht zwischen ihnen entsteht;

- eine Einheit (7) für die Zufuhr des Drahtes in den Raum (16), die oberhalb der Platte (6) angeordnet ist und einerseits ein Antriebssystem (19, 19', 20, 20') für den Draht aufweist und andererseits ein Rohr (35) um den Draht vom Ausgang des Antriebssystems zu führen, wobei die Einheit (7) in senkrechter Richtung verschiebbar ist;

dadurch gekennzeichnet, daß der Draht (17) von einem Motor M_i (26) angetrieben ist, der unabhängig vom Motor M_p (13) für den Antrieb der Platte ist, daß das Führungsrohr (35) für den Draht im wesentlichen senkrecht im Aufnahmeraum (16) angeordnet ist und daß die senkrechte Verschiebung der Zufuhreinheit (7) für den Draht mittels eines höhenverstellbaren Motors M_g (24) erfolgt unabhängig von den beiden ersteren, und daß die Vorrichtung fernerhin aufweist:

- eine Steuereinheit (3) für die Motoren (13, 24, 26) mit stufenlos regelbaren Getrieben (44, 45, 46) und einem Geschwindigkeitswähler (52) um die Ausbildung eines Signals R zu ermöglichen, das eine Sollgeschwindigkeit bedeutet und das entweder dem Antriebsmotor M_i (26) für den Draht oder dem Antriebsmotor M_p (13) für die Platte zugeführt wird;

- und eine Kontrolleinheit (2), die den höhenverstellbaren Motor M_g (24) steuert sowie den Motor M_p (13) oder M_f (26), der nicht vom Schwellensignal R gesteuert ist, wobei die folgende Beziehung erfüllt ist

$$\left(\frac{V}{W}\right)_i = \pi (D + 2d (a_i - 1))$$

in der V die Antriebsgeschwindigkeit des Drahtes (17) im Aufnahmeraum (16) (in m/s) darstellt, W die Drehgeschwindigkeit der Platte (6) (in U/s) darstellt, D und d den Durchmesser des Spulenhalters (14) bzw. des Drahtes (17) (in m) darstellen und a_i die Schicht der i-ten gebildeten Windung im Aufnahmeraum (16) zwischen dem Spulenhalter (14) und der äußeren coaxialen Hülle (15) darstellt und vom Spulenhalter aus gezählt wird.

9. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß das Rohr (35) einen Auslaßabschnitt (36) aufweist, der in Form eines "S" doppelt gebogen ist, wobei die Auslaßöffnung nach unten gerichtet ist.

10. Vorrichtung nach Ansprüchen 8 oder 9, dadurch gekennzeichnet, daß das Führungsrohr (35) für den Draht in waagrechtlicher Richtung verschiebbar ist.

11. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß die Kontrolleinheit aus einem programmierbaren Automaten (2) besteht, dessen Eingänge die Signale (F), (H) (P) zugeführt werden, die die Betriebsparameter der Vorrichtung darstellen und von Geschwindigkeitsfühlern (37, 38, 39, 40) stammen, mit denen die Motoren (13, 24, 26) versehen sind.

