Hairpin stator manufacture

Industrial proven processes applied for building prototypes

Hairpin forming                  Slot isolation

Necking & twisting              Laser welding

Scope of delivery and service offers:

• Manufacturing of A-samples for concept validation or benchmarking (lot size: 1 to 10 pcs.)
• Manufacturing of B- and C-samples for system tests and production process validation (lot size: Up to 100 pcs.)
• Design for assembly support (DFA) to optimize hairpin stator design for high scale manufacturing
• Prototype tools can directly be transferred to large scale production equipment

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Hairpin forming

Process description

The hairpin forming station is able to manufacture various different hairpin designs of U and I pins to be assembled in electric drive stators.

The manufacturing process is divided into 5 steps:

• Unwinding copper wire from coil, straightening and feeding into the station
• Remove insulation from wire at certain positions by using sanding belts
• Cutting wire pieces to certain required lengths
• Bending 2D forms with up to 4 bending angles
• Forming 3D shapes with one installed forming die, flexible to exchange for different forms

The machine concept allows quick retooling, adjustment and parameter changes to switch to different hairpin types.

Station characteristics

• 5 in 1: straightening, stripping, 2D forming, 3D forming and cutting
• Pin length 100 to 450 mm
• Up to 4 bending angles (offset correction)
• One 3D forming die installed, easy to exchange (assembly equipment for up to 6 forming dies)
• Abrasive tape used for stripping
• All parameters easily adjustable on the HMI
• Wire cross section thickness, min/max 1,1/4 (mm)
• Wire cross section width, min/max 2,3/7 (mm)
• Length of wire, min/max 320/720 (mm)
• Shoulder width, min/max 40/115 (mm)
• Cycle time 2,1 s
Hairpin stator manufacture

Hairpin and stator test

The most important quality requirement for the hairpin stator is the electrical isolation between the copper wiring and the stator laminated core. During the manufacturing of the hairpin stator two tests are executed to ensure product quality: High voltage test of hairpins and End of Line test.

High voltage water bath test

• Insulation test for detection of defects of wire coating
• Hairpin length: 100 to 450 mm
• Adjustable test voltage: 0 V up to 5 kV AC
• Tripping current adjustable: 0 to 100 mA
• Programmable ramp up
• Programmable test duration: 0,5 to 999,9 s

End of Line testing

• Surge test: max. 6 kV
• Rise time: 100 to 200 ns
• Resistance measurement with temperature compensation (range: 1 m Ohm to 100 kOhm)
• Isolation resistance up to 6 kV, max. 3 mA
• Partial discharge test according to IEC 61934/DIN EN 60034-18-41
• Withstand voltage measurement with CD/AC up to 6 kV

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Hairpin stator manufacture

Slot isolation

Process description
To ensure the electrical integrity of the stator, the hairpins have to be completely isolated against the metal laminats of the stator. Beside the coating of the hairpins, additionally a slot isolation with paper is needed for a maximum of isolation.

Automatic process:
• Unwinding isolation paper from the coil
• Continously forming the U-shape
• Cutting to correct length
• Inserting the isolation paper between hairpin and slot in the stator

Station details
• Paper width: 25 to 50 mm
• Length of stator slots: 50 to 400 mm
• Number of slots can be selected on the HMI
• Stamping/engraving of the paper before folding
• Folding while inserting into the stator core
• Stator fixture easy to adopt to the core diameter
Hairpin stator manufacture

Hairpin assembly

Process description

In the hairpin assembly station all single hairpin pallets are stacked and the pre-aligned hairpins are assembled level wise into the stator.

The following process steps are required:
• Loading the single hairpins from the buffer onto the hairpin pallet
• Transferring all hairpins from the hairpin pallet into the hairpin aligning unit
• Aligning all hairpins of a single level to the required electrical circuit
• Assemble all hairpins of each level into the stator with the help of an entering mask and a counter stay for hairpin guiding and an assembly gripper for hairpin inserting

The machine concept allows simple adaption and extension to different hairpin designs due to different electrical circuits.

Station details

• Mechanical link to multiple hairpin forming stations
• Capable for electrical circuits for 1s and 4s 3D
• Hairpin length: min/max 320/720 mm
• Shoulder width: min/max 40/115 mm
• Cycle time for each level: 8.5 s
• Robust process for different electrical circuits
• Smooth transfer of hairpins (no risk of damaging the enamel)

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Necking and twisting

Necking process
The hairpin necking unit is required to provide space in between the different hairpin levels for the following twisting process.

Technical details:
• The necking process can be performed in 2 or 3 steps
• Floating fixture and fix mounted locating unit
• Variable diameter due to different stroke
• Wire cross section thickness: min/max 1,1/4 mm
• Wire cross section width: min/max 2,3/7 mm
• Cycle time for complete necking process: ca. 20 s

The machine concept allows quick retooling, adjustment and parameter changes to switch to different hairpin types.

Twisting process
The hairpin twisting unit is required to provide the correct electrical circuit.

Technical details:
• This twisting tool can twist in both directions in level one
• Due to separate driven nc-axis, different or identical twist angles can be performed
• Special guiding of the hairpins during the twisting process
• High quality due to variable load application
• Identical wire dimensions as for the necking process
• Cycle time for complete twisting process: ca. 20 s

The machine concept allows quick retooling, adjustment and parameter changes to switch to different hairpin types.
Laser welding

**Process description**

Laser welding is the state of the art technology to join the hairpins.

Laser welding ensures:
- Small amount of heat introduction during the joining process
- Precise guiding of the joining process by controlling of laser energy, focus point and focus area
- Optimum access to the joining area

Laser welding allows flexible adjustments to different hairpin designs. Joining based on laser welding is prepared to be upgraded from prototype manufacturing to high scale production.

**Station details**

- Continuously adjustable power range at the workpiece from 120 W up to 5 kW
- Min. spotsize of laser beam about 200 µm at a wavelength of 1.030 nm
- MDE-nozzle optional to reduce the metal vapor effect and achieve the best result possible
- Camera system to automatically correct the tolerances of the hairpin positions (position accuracy about 0.1 mm)
- The programmable focusing lenses allow high speed welding processes without mechanical movements and welding distance between lenses and workpiece of 193 mm
- Welding time per hairpin from 0.1 s to 0.3 s depending on geometry of the hairpin

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