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LITERATURE REVIEW ON MANUFACTURING PROCESS OF 500Mw STATOR BARS

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Keywords:.

ABSTRACT
The per capita energy consumption in any country is an index of the living standard of the people of that country. Electric energy is an essential ingredient for the industrial and all-round development of any country. The increasing use of electrical energy in different fields of daily life has been primarily due to the availability of a vast variety of electrical machinery for the purpose of generation and utilization. It is a coveted form of energy, because it can be generated centrally in bulk and transmitted over long distances without much difficulty. This energy is obtained by conversion from fossil fuels (coal, oil, natural gas), the nuclear and hydro sources. Heat energy dissipated from the burning of fuels or nuclear fission is first converted to mechanical energy and then this mechanical energy is converted into electrical energy via generators. In power plants, these generators may be a hydro generator or a turbo generator, depending on the plant requirements.

INTRODUCTION
First of all the customer completely explains its requirements to the engineers employed in the Design. It tells the rating which they require, the voltage rating, the current rating and all other relevant information to the design engineers. Based on the requirements, the engineers develop a complete road map of the project. A drawing showing the actual dimensions of the slot and the overhang portions and all other necessary information is developed. The number of hollow and solid conductors to be used, the total number of conductors used, the type of conductor, materials to be used at all the stages of manufacturing etc. are pre-planned. The technicians then manufacture the bars based on this drawing. Hollow conductors are used in stator bars in the case of water cooled generators only (high rating).

Why do we call it a bar?
It is quite difficult (rather impossible) to manufacture, handle and wind the coil in stator slot of generator of higher generation capacity because of its bigger size and heavy weight. The shape of the coil is very similar to a solid rectangular bar. That is why we call the stator coil as stator bars. The bars are made in two parts, one is bottom part of coil called bottom or lower bar and other part of coil is called top bar or upper bar.

HG Bars: The manufacturing of bars of different capacity as required by the customer depends upon the water head available at site. The hydro generator is air cooled generator of lesser length in comparison to its bigger diameter.

Turbo – Generators: The manufacturing of bars of standard capacity such as 100MW, 130MW, 150MW, 210/235MW, 210/250MW, 500MW. The plant has the capacity and technology to manufacture 800MW and 1000MW generators.

Stator winding is the one, in which emf is induced and supplies the load. Stator winding is placed in the slots of stator core. Due to the advantages of generation and utilization of 3-phase power, three-phase winding is designed for generation. So number of slots must be a multiple of 3 (or 6 if two parallel circuits are required).
Generally, two layer lap winding, corded to about 5/6 pitch which practically eliminates 5^{th} and 7^{th} harmonics from the flux wage or open circuit induced emf wave is used. The stator coil is made up of number of strips instead of single solid piece to reduce the skin effect. The bundle of copper strips consolidated is called as stator bar. Hence stator winding involves two stages

1. Construction of stator bars.
2. Stator winding assembly with the help of bars.

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Conducting material used in coil manufacturing:
Copper material is used to make the coils. This is because
i) Copper has high electrical conductivity with excellent mechanical properties
ii) Immunity from oxidation and corrosion
iii) It is highly malleable and ductile metal.
Basically there are three types of stator winding structures employed over the range from 1 KW to 1000 MW.

1. Random wound stators.
2. Form-wound stators using multi turn coils.
3. Form-wound stators using Roebel bars.

MANUFACTURING PROCESS

1.0 DRAW CONDUCTORS FROM STORE

The conductors are taken from the store as shown in figure 6.1 and then they are cut to form bars.
The material of the conductor is **Glass Insulated Copper Wire.**
For water cooled generators, depending upon the drawing given by the engineers, different combinations of hollow and solid conductors are used. The copper conductors rolls are received is checked for physical and mechanical properties.

1.1 CONDUCTOR CUTTING AND END CLEANING

In this process, the pre insulated copper conductor is cut into number of pieces of required length (length given in drawing as per design). Insulation is removed from both ends of the copper conductor cut. It is done manually or by the automatic CNC machine. Data corresponding to cutting and processing of the conductors is fed into the processor of the machine using user interactive software. Some of the details fed into the machine along with the steps for the cutting of bars used in 500 MW generators are: No. of bars to be manufactured for each variant = 46 Conductors cutting machine is set to cut the required length of conductor. 01.The conductor is straightening through the rollers of the machine.
02.Remove self insulation of the conductor at both ends = 500 mm.
03.Cut length on the machine. Wire Length = 10200 mm
04.The same set of data will work for hollow conductors also.

1.2 TRANSPOSITION OF CONDUCTORS

“Transpose” verb: "To reverse or transfer the order or place of, to interchange; to put into a different place or order..."


Figure 1.3 Photos of a water-cooled Roebel bar with transpositions.

The complete process of conductor cutting, end cleaning and giving the bends for transposition is done by the Roebel Bar manufacturing machine shown in figure 1.1. The bend given is known as **5S bend** because it has shape of S and a radius of 5 mm. It is a complete manual process.

1. Transposition combs for both turbine end and exciter end are fixed.
2. First step of both the transposition combs must be at the same line.
3. The extreme two bending dies (used for half pitch) at a distance 2200 mm and 6566 mm from the first step of comb are fixed.
4. Intermediate die (used for full pitch) at a distance 3730 mm form the first step of transposition comb is fixed.
5. The distance between the respective dies and transposition comb is checked.
6. The conductors on the dies are set and bended for half pitch transposition.

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7. Conductor ends on comb are set for full pitch transposition and the conductor is bended by the intermediate die.
8. Conductors are taken out of transposition combs and bending dies.
9. The conductors from exciter end are equalized and transposed.

1.3 ASSEMBLY OF ALL CONDUCTORS TO BE USED IN STATOR BARS

A group of 46 conductors which are cut and bended are placed in a layer and then transposed. One such set is called as a **half bar**. The transposition process is repeated for making another half of the bar which would be mirror image of the first half. When two such bars are overlapped over each other then one final bar is formed. A spacer (epoxy glass fleece) is placed between two layers in order to avoid inter-layer shorting of the bars.

For 500 MW TG bar, the steps can be summarized as follows:

1. The conductors are transposed and clamped for rigid shape.
2. Both halves of transposed bar are superimposed in order to obtain a complete bar as per drawing.
3. Vertical spacers (epoxy glass fleece) between two halves are inserted as per drawing into the slot portion of the bar.
4. While joining two pieces of 1000 mm, vertical spacers are inserted.
5. During insertion, they should overlap by 50mmby making taper joint.
6. The conductors are dressed up and clamped again.
7. Identification number of the bar is punched at the exciter end of the bar.

1.4 CROSS OVER INSULATION

The pre insulation of the copper conductor may get damaged due to mechanical bending in die during transposition, hence the insulating spacers are provided at the crossover portion of the conductors. A filler material (insulating putty of molding micanite) is provided along the height of the bar to maintain the rectangular shape and to cover the difference of level of conductors. To eliminate inter turn short at bends during edge wise bending and leveling of bars in slots portion for proper stacking.

1.5 STACK CONSOLIDATION/PRESSING

The core part of the bar stack is pressed in press (closed box) under pressure (varies from product to product) and a high temperature is maintained for a given period. The consolidated stack is withdrawn from the press and dimensions are checked.

A bunch of bars (number varies according to the ratings) are heated and pressed and then cooled to remove all the air gaps and to attain perfect dimensions. It is done by HF Stollberg CNC Hydraulic Press Machine. For 500 MW turbo generator stator bars as the complete process is:

1. Press is prepared for loading of bars. Minimum 5 bars are put inside the machine for 350 MW but for 500 MW, only one bar is pressed at one time.
2. The press planks are cleaned.
3. One bar is loaded on each tier of heating plates wrapping the bar with silicon coated release films.
4. Press planks are kept on both sides of the bar along the length and the box is closed.
5. Vertical pressing is followed by horizontal pressure.
6. Heating is started and a low pressure of 35 +/- 5 kg/cm^2 is applied on the bars (gauge pressure).

1.6 PICKLING OF BAR ENDS

In B.H.E.L., for 500 MW turbo generator stator bars, both the stator bar ends are passed through various chemicals. This process can be enlisted as:

1. Bar ends are passed through a solution consisting of **Water** (100 parts by weight), **Sulphuric Acid** (10 parts by weight), **Phosphoric Acid** (5 parts by weight) and **Hydrogen Peroxide** (5 parts by weight).
2. It is dipped in **water** to wash all the acids used earlier.
3. Then it is rubbed with a **Brass** brush to clean it. **Liquid Ammonia** solution consisting of water (100 parts by weight) and liquid ammonia (10 parts by weight) is used next. It is used to remove the traces of acid left and neutralizing all the acidic properties.
4. Then it is dipped into **Ethyl Alcohol** to maintain the brightness of the bar ends.
5. On its completion, compressed air is passed through both the end so that pickling solution is not left out in the hollow conductor.

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6. Now the pickled portion is wrapped with clean cotton cloth and it is tied.
7. All the copper components and strip of copper sheet contact sleeve and water box bottom parts are pickled and these should not be touched by bare hands.

1.7 PICKLING OF BAR ENDS

After brazing and mounting of bottom part of water box, the material loses its shine. So to regain its color, the contact sleeve and water box is passed through some chemicals. This complete process is called pickling of bar ends.

For 500 MW turbo generator stator bars, the stator bar ends are passed through all the chemicals used before mounting and brazing of contact sleeve and bottom part of water box.

Bar ends are passed through a solution consisting of **Water** (100 parts by weight), **Sulphuric Acid** (10 parts by weight), **Phosphoric Acid** (5 parts by weight) and **Hydrogen Peroxide** (5 parts by weight) or, It is dipped in **water** to wash all the acids used earlier.Then it is rubbed with a **Brass** brush to clean it. Brass is used because if we use iron at its place then a blue color will appear on its surface because of chemical reaction between the two.

1.12 WATER FLOW TEST

A water flow test is an ultrasonic test of the water flow rates in the stator cooling system of water-cooled generators. It detects the cooling circuit blockages and choking present in the generator windings. We can perform this test during any maintenance outage during which the inner and outer upper half end shields are removed.
In this test, water is passed through one end of the bar and is allowed to flow through the hollow conductors at the other end of the bar. All hollow conductors must be clear so that the water flows without any obstruction through them.

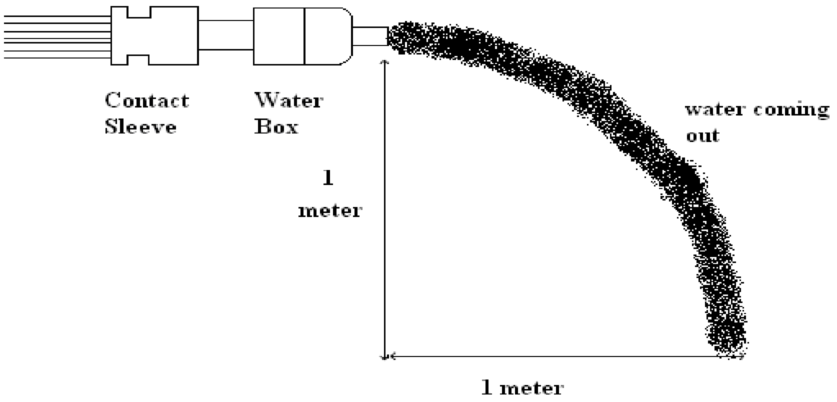

Figure 1.5 Water Flow test

The level of clearance of the conductors is judged on the fact that if the water box of the bar is kept at a height of 1 meter from the ground then water must fall at a horizontal distance of 1 meter from the water box or the bar end, provided the initial rate of flow is kept at a predetermined value, which further depends on the number of conductors used, their length, the overhang profile, etc., as shown in the figure 1.6.

1.13 NITROGEN LEAKAGE TEST

It is done to check if some leakage is present in the bar, as well as to remove all the traces of water present in the bar left during the water flow test. The main reason for using nitrogen is that nitrogen has an affinity for water, and facilitates drying. It cleans the entire internal surface of the hollow conductor.
After nitrogen test, fixtures are removed from both ends and nitrogen gas is blown. The water box bottom part is wrapped with clean cotton cloth.

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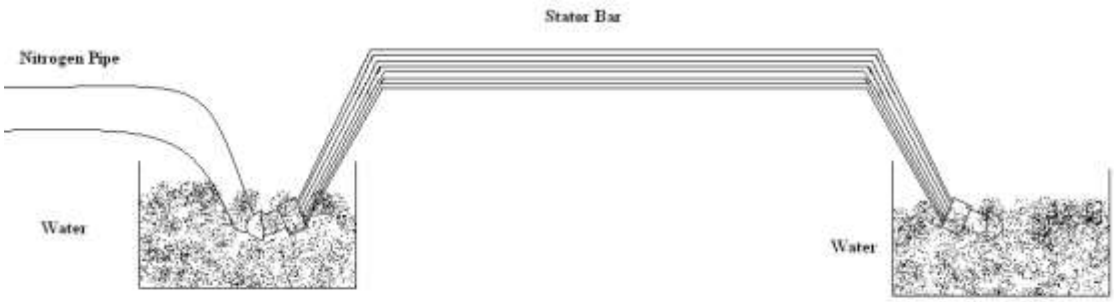

Figure 1.6 Nitrogen test

After nitrogen test, a group of 6 bars is taken and pickling acid is passed through them. This process is known as **Internal Pickling.**

1.14 THERMAL SHOCK TEST

Large motors are exposed to frequent start/stop operations. Pumped-storage generators and hydro-generators have frequent load changes. All of those operations cause rapid heating and cooling, i.e. thermal cycling effect on stator insulation. Thermal cycling can cause

- Loss of bond between copper and insulation;
- Delaminating and degradation of ground wall insulation;
- Insulation failure.

For 500 MW turbo generator stator bars, 26 cycles of hot water (80°C - 100° C) and cold water (below 30° C) are flown through the bar to ensure the thermal expansion and contraction of the joints. The experimental setup for the test is shown in figure 6.8. This regular expansion and contraction can lead to leakage in the bar. If some leakage is there, then the bar fails this test otherwise it is passed for the next test, the helium leakage test. Maximum six bars can be processed at a time. After completion of this test, nitrogen gas is blown through it for removal of any traces of water present in the conductors. The bars are evacuated to 0.10 torr for one hour to remove traces of moisture. Main precaution in this test is that a proper sequence of hot and cold water must be maintained.

1.16 REFORMING OF BAR (i.e. OVERHANG PORTION)

All these tests normally spoil the diamond shape of bar. So to regain the shape, forming is done again. It is a total manual process and is done on the Former. Some of the specifications used for forming of 500 MW are
Conductor end = 1000 mm
Contact sleeve position = 890 mm

1.17 INSULATION OF BARS

High voltage insulation systems for rotating machines are a very complex combination of materials with different functions.

1.17.1 Insulating Materials:

Insulating materials or insulators are extremely diverse in origin and properties. They are essentially non-metallic, are organic or inorganic, uniform or heterogeneous in composition, natural or synthetic. Many of them are of natural origin as, for example, paper, cloth, paraffin wax and natural resins. Wide use is made of many inorganic insulating materials such as glass, ceramics and mica. A good insulating material needs the following properties:

1. The basic function of insulation is to provide insulation live wire to live wire or to the earth.
2. It should be good conductor to heat and bad conductor to electricity.
3. It should withstand the designed mechanical stress.
4. It should have good chemical and thermal resistively and environmental resistively.

1.17.2 Insulating Material for Machines

Different types of materials can be used for the machines. Some of the commonly used insulating materials are:

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Table 1.1 Insulating materials for machines

Name of Material	Insulation Class	Shelf Life (In months)		Application
		At 20 ° C	At 5° C	
1. Samicatherm calmica glass-n, mimica, domica, folium, filamic novobond-s, epoxy therm laxman isola calmicaflex	F	6	12	Main insulation of stator bars
2. Samica flex	H	4	8	Overhang insulation of motor coils, at 3rd bends of multi turn coil
3. Vectro asbestos (365.02/365.32) 4. (used in resin rich)	B/F	2	8	Main pole coils of synchronous machines
5. Epoxide pepreg glasscloth	F	6	12	Winding holders and interhalf insulation
6. Polyester resin mat & rope		6		Bar to winding holder&stiffner groove of support segment of clamping plate
7. Glassoflex Turbo laminate	F	6	12	Interturn insulation of rotor winding
8. Hyper seal tape	F	6	12	As finishing layer in overhangs of motor coils
9. SIB775 or 4302 varnish	F	6	12	Stack Consolidation of stator bars
10. SIB475 or 4301 varnish	F	6	12	Base coat varnish before taping of stator bars
11. SIB 643 or8003 Varnish or K8886 varnish		4	8	Conductive coat in straight portion of stator bars
12. SIB 642 or 8001 varnish		4	8	At slot emerge portion on stator bars

1.18 IMPREGNATION AND CURING OF BAR INSULATION

1.18.1 Varnish:

This is most effective type of insulation now available. It makes the laminations nest proofs and is not affected by the temperature produced in electrical machines varnish is usually applied to both sides of lamination to a thickness of about 0.006mm. On plates of 0.35mm thickness varnish gives a stacking factor about 0.95.

In order to achieve good insulation properties the following processes are there.

- Thermoplastic Process of Insulation
- Thermosetting Process of Insulation

BHEL is practicing only thermosetting process of insulation.
Thermosetting types of insulation are of two types:

- Resin Rich System of Insulation
- Resin Poor System of Insulation

S. No.	Process	500 MW / TARI Individual Bar with or without	THRI/ TARI

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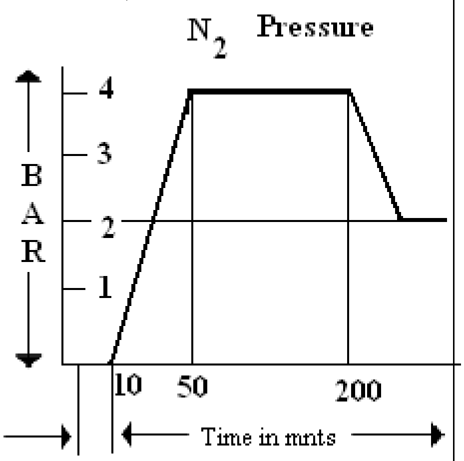
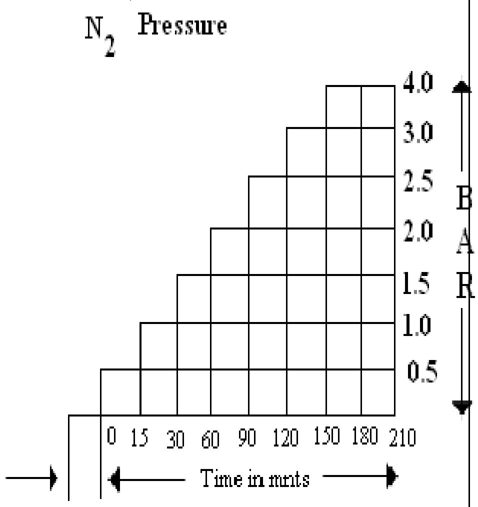
1.	Heating	30 +/- 5° C	65 +/- 5° C
2.	Evacuation (vacuum impregnation)	0.5 mm bar For maximum 5 hrs	0.5 mm bar For maximum 5 hrs
3.	Maintain Vacuum	0.2 mm bar or less preferably 0.1 mm bar for maximum 2 hrs	0.2 mm bar or less preferably 0.1 mm bar for maximum 2 hrs
4.	Hold temperature for		
4.1	Minimum Heating	10 hrs	10 hrs
4.2	Maximum Heating	12 hrs	12 hrs
5.	Ensure (Before transferring)		
5.1	Resin Temperature	70 +/- 3° C	65 +/- 3° C
5.2	Resin Vacuum	20 minutes	20 minutes
6.	Total Cycle time in achieving and holding temperature	Not to exceed 24 hrs	Not to exceed 35 hrs
7.	Apply Nitrogen Pressure (Gradually and hold as per scheme)	140 +/- 5° C, 8 hrs 	140 +/- 5° C, 8 Hrs 

1.21 TESTING
1.21.1 Delta Test
Before performing tan delta test and high voltage test, the stator bars are covered with some special tapes and materials. The conducting varnishing tape is used on the stator bars. The viscosity of this varnish must be 30-35 mm. It is filled in a cup and then allowed to pass through a hole at the bottom. The time taken to flow gives a measure of viscosity of the varnish.

Aluminum adhesive tape is laid along both the height surface of bar without air voids.
They are tightly held on the bar surface with ½ mm thick insulating packing strip and then tied with cotton tape by spiral taping.Two turns of adhesive aluminum tape are tied keeping approx. 1-3 mm gap from conducting coated length. The length of this gap may vary from half of the thickness of layer of insulation. It is the minimum gap.

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Semiconducting polyester tape is applied from the second turn of adhesive aluminum tape extending second bend portion. Taped length with semi conducting tape will be approximately 600 mm. This semiconducting polyester tape is used at the bends to avoid corona. This process is called ECP and it is removed after testing is done.

While taping second layer, 100 mm distance to be kept from first layer. Similarly remaining three layers are applied at 100 mm from the previous layers.

Since test voltage is 64.5 kV which is very close to upper limit of voltage. So next higher voltage is opted for taping of semiconducting tape.

CONCLUSION

The complete manufacturing process of the turbo-generator stator bars is quite tedious. It involves a lot of processes, with each process having its own advantages. All of these processes have been discussed in detail in the report. Many of these processes depend upon the rating of the generators. Higher is the rating, more complicated is the process of manufacturing the bars. All of these processes are quite sensitive where even small mistakes are not permissible. If the bars are not of exact dimension, they won't fit in the stator slots completely and therefore vibrations will increase. If the overhang profile is not accurate, there will be a problem in making electrical connections as well as cooling. The bars must pass the series of tests performed. There must not be even a minute leakage present in the hollow conductors. The insulation should be proper and proper materials must be used for them. Air gaps shouldn't be present in the bars otherwise it can be hazardous. Each and every material used at various stages of production has their own advantages.

After the bars undergo all these processes and pass all the tests, they are sent to turbogenerator manufacturing block for stator windings.

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