Transrapid Motor Cable Mounting Technology

(*) Dr.-Ing. Xiufei Liu,  (**) Jürgen Braun
ThyssenKrupp Transrapid GmbH, Moosacher Str. 58, 80809 Munich, Germany
(*) +49 (89) 35 46 9-159 /-148, xiufei.liu@tkt-tr.thyssenkrupp.com
(**) +49 (89) 35 46 9-158 /-112, braun@tkt-tr.thyssenkrupp.com

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Abstract
Two kinds of vehicles for mounting of the grounding system and the LSW motor cables were developed by the ThyssenKrupp Transrapid Company for the Shanghai Maglev Project respectively. This article describes the construction of the mounting vehicles and the mounting procedure for the grounding wire and the grounding sleeve as well as for the motor cable bending, crimping and mounting. The performance and characteristics of the vehicles and mechanical components are introduced.

Due to a new concept, the mounting speed is considerably increased. By using many standard components the costs could be largely reduced. Furthermore, the reliability and maintainability of the mounting vehicles is markedly increased and the operation and handling is clearly simplified.

Within six months from concept determination via specification, engineering design, manufacturing, assembly, commissioning, training of operator personnel to start of motor cable mounting the mounting vehicles were put into operation and completely verified during the LSW-motor cable mounting program. Within the first hours of operation the specified performance and parameters were fully reached.

1 Introduction
The long stator is the stationary part of the linear motor nested in the Transrapid guideway. This system consists of long-stator-packs, grounding wire, grounding sleeves and LSW-motor cable (fig. 1). The grounding sleeves and the LSW-motor cables will be mounted in the groove of the long-stator-packs which are mounted on both sides underneath the guideway. The grounding wire made of stainless steel connects all grounding sleeves. Three phases of the LSW-motor cables with individual shape are required for the long stator winding [1].

Based on the accumulated experience two kinds of mounting vehicles for the Shanghai Maglev Project were developed. While the first vehicle (Module 1) is used to mount the grounding sleeve and grounding wire, the second mounting vehicle (Module 2) is applied for bending, crimping and mounting the motor cable into the grounding sleeves.
Fig. 1 Long stator winding with 3 phases nested in the Transrapid guideway.

With the previous mounting vehicle which was designed for the test Track in Lathen, Germany the components of the motor winding could be installed only on one side of the guideway. The mounting vehicle had to be turned over or reintegrated on the track for the installation on the other side. With the new mounting vehicle the motor cable mounting can be done flexibly on either sides of the guideway increasing the mounting efficiency. Furthermore, the new vehicle enables the mounting on the outside of the guideway during the Transrapid operation on the other track. The reliability and maintainability of the mounting vehicle are farther improved and operation and handling are more simplified. The protective measures for weather condition and working space as well as the influence of the large inclination of guideway in longitudinal and transverse directions on the working situation are considered. Above all working safety has been carefully taken into account [2].

2 Mounting Vehicle for Grounding Sleeve and Grounding Wire

2.1 Mechanical properties of Module 1

The purpose of Module 1 is to install grounding sleeves in the long-stator-packs, to connect the grounding sleeves with the grounding wire and to fix the grounding wire to the guideway. Module 1 consists of 1 pulling unit, 4 trailers, 4 transitions, 6 walkways with 10 adjustable housings, 1 lift and 1 pen, as fig. 2 shows. The space on the first and third trailer is used to store the grounding components. The container on the second trailer provides a room with wooden tables, benches, lighting, sockets, fire extinguishers, a first aid box, a water tank and washroom equipment. The lift on the fourth trailer is the personnel access between mounting vehicle and ground. Railings are available on every side of the trailer which are connected by transition. The pen at the end of Module 1 is used to protect the workers fixing the grounding wire on the guideway. Emergency-stops are installed to stop the vehicle so that workers can escape by rope under emergency conditions.

The total length of Module 1 is about 46 m, operation width 5.6 m, non-operation width 3.69 m, and height is 3.3 m from the surface of the guideway. Three walkways are connected end to end to form a working platform with a length of 31 m and width of 1.5m under the guideway. In non-operation state Module 1 can move on the track with a maximum speed of 25 km/h.

The grounding components can be mounted on both sides of the guideway at the same time. In operation state Module 1 runs at constant speed, the grounding sleeves are manually pushed in the grooves of the long-stator-packs by the workers who are sitting on a mountable working bench with adjustable height.
With a special tool the grounding wire is pushed in the connection groove of the grounding sleeve and the grounding wire is fixed to the guideway. The communication system between the driver and working group leader enables Module 1 to run at a suitable speed (about 80 m/h to 240 m/h). At last step the mounting quality will be inspected and logged.

### 2.2 Mechanical equipment of Module 1

The Unimog (fig. 3) produced by the Mercedes Benz Company is used as the pulling unit with a speed range from 48 m/h to 25000 m/h. The low speed is operated during the mounting procedure. Additionally the Unimog is equipped with a diesel generator for electrical energy supply, diesel storage tank connected to the Unimog tank and generator tank, locked steering wheel, lateral roller guidance, safety fences and walkways on both side. Two compressed air accumulators on the Unimog connect the brake device of each trailer. The compressed air accumulators of the trailer ensure the brake action continuously for at least three times. If the pressure of the compressed air falls below the lower limit, Module 1 will be stopped automatically.

The trailer is one of the most important working machines carrying all equipment and personnel. Two tandem axles with 4 supporting shafts and 8 wheels made of solid rubber ensure the required load capacity. Two sets of lateral guidance wheels are mounted on its front and rear side. The gap between the lateral guideway surface and lateral guidance wheel is designed that the trailer can not be blocked at the tightest curve of Transrapid route. Safety railings are installed in all necessary places on the trailer.
Walkways on both sides of the mounting vehicle provide the working place for mounting the grounding components. A safe and comfortable working environment is very important to guarantee mounting quality and speed. The working space can be enclosed after the walkways and housings spread out. It can not only guarantee the safety of workers, but also protect against weather conditions. The housing on the walkway is made of plastic tarp with 65% transparency. Mountable working benches are fixed on the walkway underneath the long-stator-packs. Each walkway has a mountable ladder used as access between walkway and trailer.

The movement of the walkway in turning and vertical direction is driven by hydraulic cylinders. A series of hydraulic valves is used to balance the walkway movement in vertical direction. Hydraulic accumulators keep the proper walkway position in operation state. Hydraulic fixed pipelines on trailer and soft pipes with quick tie-in on the transition connect the hydraulic supply unit on the first trailer to the control panel for each walkway. For safety the control panel can be operated only with two keys at the same time.

A transition connecting the trailers is shown in fig. 4. These enlarge the working and storage area on Module 1. The connection between the transition and trailer enable the relative movement along the curved track. The electrical cable and compressed air pipe are lied under the transition.

Five housings are mounted on each side of Module 1. Three of them are mounted on the trailer and two on the transition. Using a worm gear transmission the housing can be safely and quickly opened or closed due to the self-locked function of the worm gear. Sockets for power supply and emergency stop buttons are accessible on the housing frame. In non-operation state the housing will be fixed by local devices to prevent the vibration caused by the aerodynamic pressure from a passing Maglev vehicle. Descending of the walkway, which could possibly result from leakage of hydraulic accumulator after being closed for a very long time, are prevented by the mechanical interlock measures.

A special lift on the forth trailer permits the access of personnel from the road to the working modules and from the modules to the ground, when the mounting vehicles stops arbitrarily on the guideway. The maximum height range of this lift is 12 m from the surface of the guideway. Three access segments with safety railing adjust the local range height from guideway to ground. The lateral flexible platform driven by motor and the rotatable supporting of the segments enable the lift to be applied on the inclined guideway. (fig. 5). After three segments and the flexible platform are completely retracted, the lift will be fixed to the trailer by a rod with adjustable length to avoid it swinging on inclined track (fig. 6). The mounting vehicle can not be moved until a signal is transmitted to the driver indicating the lift to be in completely retracted state.
The lift is operated by radio control, each lift being equipped with a special code controller in hand. The power supply of the lift is a set of accumulator. The rechargeable battery enables the personnel on the ground to use the lift before the main generator on the Unimog is started. On the other hand the lift is available for personnel on board who are leaving off work when the generator has already been shut down.

### 2.3 Stability analysis of mounting vehicle under worst case conditions

A passing maglev vehicle causes an alternating aero-dynamic pressure around its environment. The pressure distribution had been measured with sensors in different positions on the flank of a Transrapid vehicle standing still on the track while another Transrapid vehicle was passing by on the other track. The measured peak pressure amounts up to 1200 Pa. The lateral dynamic force resulting from this pressure affects the stability of the mounting vehicle on track especially in the largest inclined guideway.

Under unfavorable conditions the stability of the mounting vehicle was investigated. The most unfavorable conditions are: 1. the largest aerodynamic pressure from passing maglev vehicle; 2. the largest guideway inclination; 3. additional strong lateral wind; 4. guideway covered by ice, thus the friction coefficient being equal to zero; 5. large eccentricity of the mounting vehicle.

Fig. 7 shows schematic the action and reaction force on the Unimog. The normal reaction force of the left wheel is:

\[
F_{LY} = \frac{1}{B} \left[ mg \cdot \cos(\alpha) \left( \frac{1}{2} B - c \right) + \mu \cdot R_{LY} \cdot h_3 - F_w \cdot (h_2 \cdot \cos(\alpha) + B \cdot \sin(\alpha)) - mg \cdot \sin(\alpha) \cdot h_1 - R_{LY} \cdot h_3 \right]
\]

If the reaction force \( F_{LY} \) is equal to zero, the mounting vehicle on the track becomes instable. Fig. 8 gives the reaction force variation depending on the lateral wind velocity under worst case conditions. The result is that even under the typhoon condition Module 1 stays safely on the track. A similar analysis can be made for all trailers. The calculation shows that the mounting vehicle remains in a stable position even under worst case conditions.
3 Mounting Vehicle for LSW-Motor Cable

3.1 Mounting Procedure of LSW-Motor Cable

The second vehicle (Module 2) (fig. 9) is used to mount the LSW-motor cable. It consists of 1 pulling unit (Unimog), 1 trailer for cable drums, 1 trailer for bending and crimping device, 1 trailer for push-in unit and 1 lift. The first trailer carries two cable drums with a capacity of 6000 m. One drum (3000 m) is used during the mounting process, the other is used for storage to reduce non production time during exchange of empty cable drums. This trailer is completely enclosed by a moveable housing to be prepared for any weather conditions.

The second trailer of Module 2 carries the bending and crimping device to produce the individual shape of the upper, middle and lower phase. This device includes the control panel and the hydraulic supply for the other trailers. This trailer is equipped with a housing, lateral roller guidance and a conveying system which is connected to trailer 3.

The motor cable is automatically unwinded from the cable drum and fed-in through the cable loop device to the bending station. The cable loop device is used for buffering the motor cable to compensate the discontinuous feed-in in the bending station. The cable loop is basically controlled by two limit switches. As soon as the cable loop becomes too small it will activate a limit switch and starts automatically the rotation movement of the cable drum thus enlarging the cable loop. In addition a cable caterpillar is used to pull the cable from the cable drum into the cable loop. This cable caterpillar clamps the motor cable between two driven belts. When the cable loop has reached a defined maximum, the other limit switch will shut off the cable drum rotation immediately. By this control mechanism the optimum cable length of the motor cable loop is realized at all time, allowing a high production speed of the bending process.

The third trailer carries a container on the top and on the bottom the push-in unit. The push-in unit is located on a separate moving vehicle which is placed between the front and rear wheels of trailer 3. The semiautomatic push-in unit is used for mounting of the formed motor cables (meanders) into the grooves of the stator packs. Additionally, trailer 3 is equipped with an enclosed walkway on both sides for the operator, a conveying system for the produced meanders and a vertical movable lift to access the mounting vehicle from the ground. The total length of Module 2 is about 40 m, extended width is 5.6 m, with 3.8 m height from the surface of the guideway.
3.2  Motor cable bending and crimping device

Basically there are two numerical controlled axle directions for bending the meander in horizontal layer (fig. 10). One axle is for x- and one for y-direction. Each axle is realized through a numerical controlled ball screw driven by a variable frequency drive motor. The width and length of the u-shape is completely adjustable through the operator panel by the control unit. In order to get the u-shape of the meanders there are three bending heads necessary. The first and the second bending head are able to move in x- and y-direction to adjust the various length during the bending movement. The third bending head is only able to move in y-direction together with the second bending head simultaneously. All three bending heads are equipped with grippers for holding the cable during the bending movement.

In the next cycle the u-shape is transported to the crimping station. The crimping of the meander is necessary to get the individual shapes for each motor cable phase. Basically there are also two numerical controlled axles for crimping the meander in vertical direction. One axle is for y- and one for z-direction. The z-axle is equipped with a crimping head. The crimping heads are exchangeable for different phases. The crimping head moves the cable against upper positioned down holders during the crimping movement. In the next cycle the produced meander is transported over a conveying system to the push-in unit.

3.3  Push-in unit

Before the meanders are ready to be pushed into the grooves of the stator packs they are being semi-automatically transported and separated by a chain conveyor in front of the push-in unit. The separation is done by openings on the supports of the chain conveyor. By each opening the meander can fit exactly in the gap and gets prepared to be transported to the push-in cylinders and gets prepared to be pushed in, too.

With the push–in unit the produced meanders are mounted semiautomatically into the grooves of the stator packs. For the positioning of the push-in unit there are sensors with laser technique. They show the operator the correct position. For a correct position of the meanders there are pivoting guidance plates on both sides of each push-in cylinder. During the feed-in of the meanders the pivoting orientation plates are opened to a horizontal orientation. Before the push-in process gets started the pivoting plates are closed into a vertical orientation (fig. 11).

The push-in process can be started manually if the push-in cylinders are in the middle of the grooves. Four grooves can be operated at the same time to reach an average speed of about 1.25 m/min.
3.4 Strength and stiffness analysis of the mechanical equipments

Not only the strength but also the stiffness of the important mechanical components are investigated. As an example fig. 12 shows the calculated results of deformation distribution in the housing frame of the second trailer. The measured maximum aero-dynamic pressure is used as load for the FE-Method calculation. The analysis results give a large safety margin for strength and stiffness.

4. Performance Results for the Shanghai Maglev Project

These two kinds of mounting vehicles have been successfully developed within time schedule. After commissioning Module 1 and 2 were immediately put into operation to mount the grounding components for the Shanghai Maglev Project (fig. 13). A Module 1 is running ahead of a Module 2 on track, and both modules are applied as an unit. Personnel shift and logistics were successfully accomplished fully according to the mounting program.

Just within the first hours of operation the specified performance of the new mounting vehicle was clearly reached for the upper layer and the desired mounting performance could be met. The new developed mounting vehicles were fully verified during the LSW-motor cable mounting program, and the mounting procedure could be finished within the time schedule.
Fig. 14 a and b show respectively the statistic results of the mounting performance and velocity of the lower layer in practice. The maximum mounting speed of Module 1 has been reached about 4 m/min, and Module 2 about 2.1 m/min. The average output of Module 2 was 1.27 m/min. The specified goal of the average output of 1.25 m/min has been successfully attained, due to the joint efforts of the ThyssenKrupp Transrapid company and the Shanghai Maglev Transportation Development Company (SMTDC).

Fig. 14 a Mounting performance and b mounting velocity of the lower layer.

5. Conclusion

Two kinds of mounting vehicles for long stator winding have been successfully developed. By using the new concept the average mounting speed has been increased from 0.5 to 1.25 m/min. The new concept was completely verified during the LSW-motor cable mounting program, and the specified performance and parameters were fully reached. The new mounting technology developed by the ThyssenKrupp Transrapid company contributed to the reduction of system installation time and to the improvement of economic feasibility of Transrapid technology [3].

References

