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MEASURING THE HYSTERESIS LOOPS OF TWISTED CORES

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Abstract: A new type of SZ-stranding machines was developed at the Institute of Machine Elements and Machine Design. For the design of the stranding machine it was necessary to measure the occurring forces during the stranding process. Additionally it is from paramount importance to determine the required stranding torque.

Therefore a test bed to simulate the stranding process for one insulated conductor was built up. This offers the possibility to record rotation angle and corresponding torque simultaneously during only one measurement procedure.

Evaluation occurs computer-assisted, the hysteresis loops are created with the aid of spreadsheet routines. Interpretation of the hysteresis loops gives important hints for the design of the stranding head and the lay storage.

Keywords: Hysteresis loop, conductor, core

1 INTRODUCTION

Compared to conventional stranding machines SZ-stranding machines offer higher stranding velocity and therefore higher productivity during cable production [2-4]. In this procedure both, the conductor drums and the cable drum are stationary. This leads to a reduction of inertia and therefore higher rotation speed is possible.

For design of the stranding machine (drive motor, stranding head, lay storage), it was necessary to establish the occurring maximum force and maximum torque in test bed measurements of different cores. To determine the hysteresis loop (torque dependent on rotation angle) a test bed (see section 2) was built up.

2 TEST BED

The test bed (see fig. 1) consists of a fixing device (1), the test core (2) and the dowel bushes (3) for different cores as well as the measuring equipment. This consists of a torquemeter (4), a measuring amplifier (5) and the connected personal computer (6). The link between the test core and the torquemeter takes place with the aid of a connection link (7), which is also used for the optical display of the rotation angle (8).

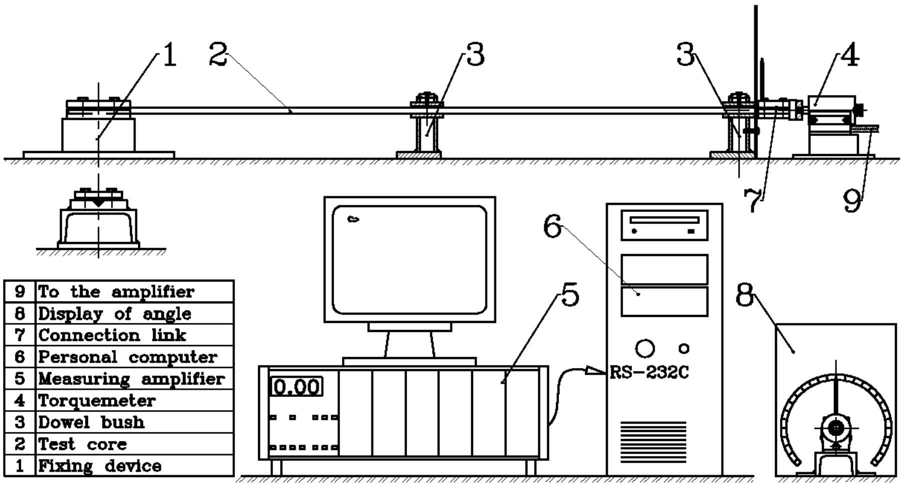

Figure 1. Equipment for measuring the hysteresis loop of isolated sector-conductors under torque

3 TESTING PROCEDURE

The isolated sector-conductor (to be measured) with cross-sections between 25 mm^2 - 90 mm^2 and different materials (aluminum and copper) as well as different construction of the metallic conductor (single wire, multi wire) is inserted into the test bed according to Fig. 1. In order to simulate an entire SZ-stranding process the core is twisted 180° clockwise first. Afterwards the core is twisted back to -180° and finally turned into the starting position again. At this stage, the hysteresis loop has passed through once (see results in Fig. 2). The results of measurement (torque and rotation angle) are automatically written on a file and later evaluated by means of a computer program (MS-EXCEL®).

4 HYSTERESIS LOOPS

Illustrations 2a and 2b show examples of measured hysteresis loops. The hysteresis loop demonstrates the correlation of torque and angle of rotation. The area of the hysteresis loop is a value for the required twisting work and a value for the plastic deformation of the specimen. A small area means nearly elastic material behavior (Fig. 2a right and Fig. 2b) whereas a big enclosed area signifies strong plasticity (Fig. 2a left). The stronger the plasticity of the conductor material, the longer the lay storage, so that the cores remain in the elastic range during the stranding process.[5-7]

Moreover the elastic angle of rotation $j_{el.}$ and the maximum torque $\mathbf{M_{max.}}$ can be picked out of the hysteresis diagrams directly. The maximum torque is used for the calculation of the drive motor and the stranding head. Otherwise the elastic angle of rotation respectively the area of the hysteresis loop is needed for the optimization of the geometrical design of the lay storage.[1]

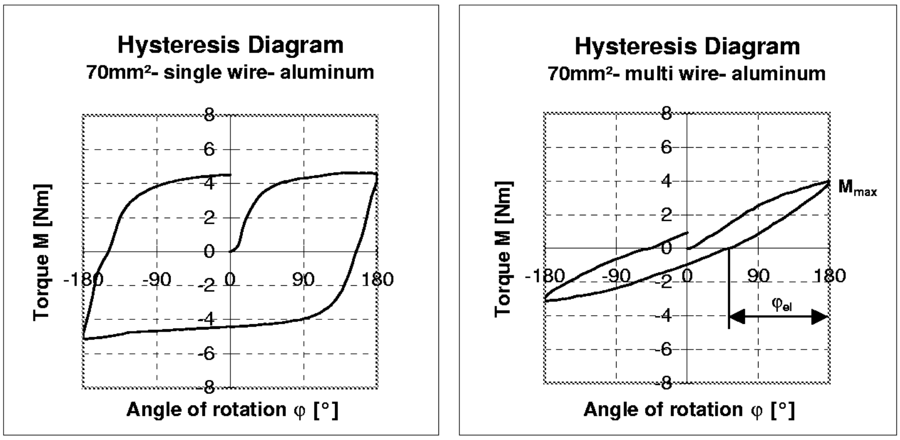

Figure 2a. Hysteresis loops for insulated aluminum sector-conductors with 70 mm^2 cross-section single wired (left) and multi wired (right).

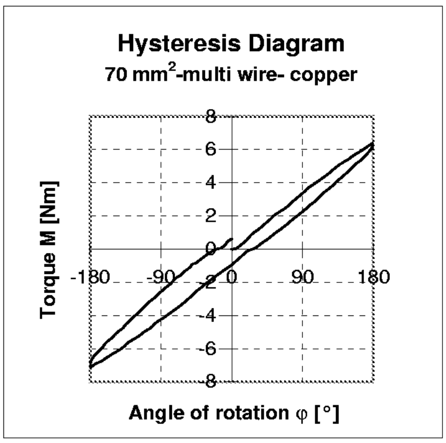

Figure 2b. Hysteresis loops for insulated copper sector-conductors with 70 mm^2 cross-section multi wired

4.1 Calculating the area of hysteresis loops

To evaluate the area– surrounded by the hysteresis line– of each measured hysteresis loop the following equation (1) is used.

$$\sum_{i=0}^{n}\left(\left(j_{i+1}-j_{i}\right)\tfrac{p}{180}\right)M_i+\frac{\left(M_{i+1}-M_i\right)\left(j_{i+1}-j_{i}\right)\tfrac{p}{180}}{2} \qquad (1)$$

The total area of the hysteresis loop is calculated by integrating the small rectangles, which build up the whole loop shown in figure 3. Because the loop consists of many measurement points it is possible to calculate the whole area with sufficient precision. This is done by summation of the rectangles, see figure 3.

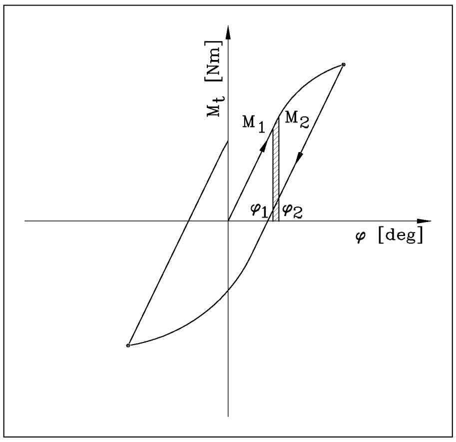

Figure 3. Calculating the area of a hysteresis loop

Table 1 shows further details (construction type, area of the different hysteresis loops...) of these measurement results. The maximum area of the hysteresis loop occurs with unifilar aluminum cores, which plasticize strongest and require the most deformation work while stranding. On the other hand the multi wire aluminum and copper cores show the smallest hysteresis face and are consequently the most elastic ones. To get small deformation of the conductors during the stranding process, the lay storage should be designed by using the measurement results of the core with the biggest hysteresis face. This leads to a long lay storage with small conductor deformations and offers good cable- and stranding qualitiy. But the big disadvantage is, that it requires much more space.

Thus the unifilar (single wire) aluminum conductor with 95 mm^2 cross-sectional area was chosen for the design and optimization of the lay storage.

Table 1. Calculation results of the area of the hysteresis loops

Conductor-Cross section [mm^2]	**Construktion Type**	**Material**	**Area of the Hysteresis Loop [Nm·rad]**
50	Single wire	Aluminum	24.13
70	Single wire	Aluminum	40.10
95	*Single wire*	*Aluminum*	*83.63*
35	Multi wire	Aluminum	2.96
50	Multi wire	Aluminum	4.40
70	Multi wire	Aluminum	8.39
95	Multi wire	Aluminum	18.99
35	Multi wire	Copper	3.14
50	Multi wire	Copper	2.45
70	Multi wire	Copper	7.33
95	Multi wire	Copper	28.59

4.2 Passing through the hysteresis loop more than one time

During the stranding process the cores are twisted in alternating senses of rotation for three or more times. For the design of the lay storage it is necessary to know if there are hardening effects, because the length of the lay storage is a function of the elastic or plastic behavior of the different insulated conductors. Hardening effects lead to the result that the hysteresis loop would get bigger and its area would increase after each step (loop).

The torsion test, described in section 3, was made in the same way, with the only difference that the hysteresis loop was passed through three times instead of only one time. The test results of the insulated 70 mm^2 conductors (single and multi wire, aluminum and copper) are shown in figures 4a and 4b. All tests show that hardening effects have hardly an influence on the appearance of the hysteresis loops. The total area of the loop passed through three times has nearly the same area as the loop which passed through only one time.

Therefore it is possible to use the test results of the single passed hysteresis loops without restrictions, to get accurate results for the optimization of the lay storage.

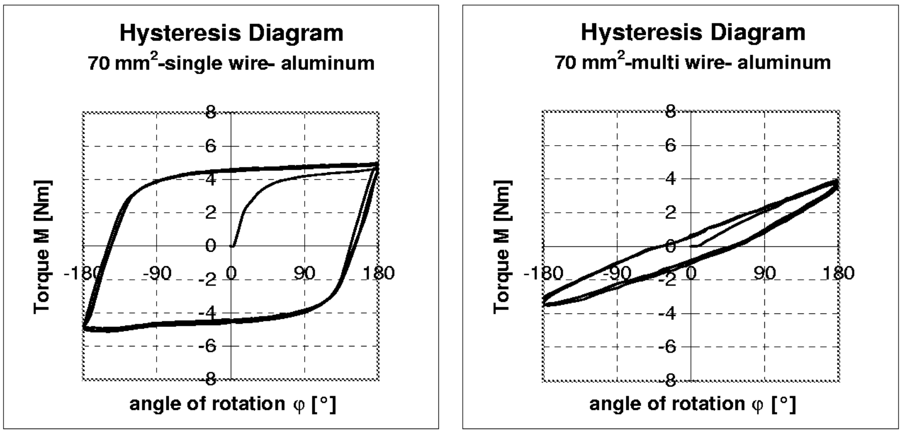

Figure 4a. Hysteresis loop passed through 3 times, aluminum, single wired (left) and multi wired (right)

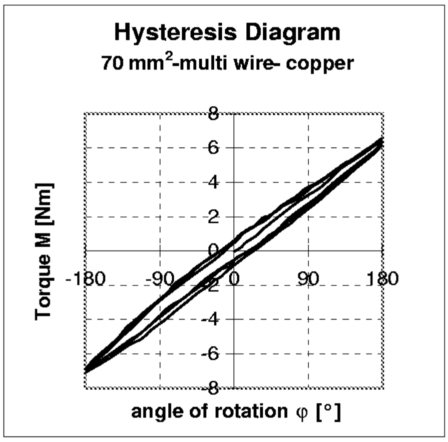

Figure 4b. Hysteresis loop passed through 3 times, copper, multi wired

4.3 Measurement results

4.3.1 Maximum torque

The following figures present the connection between the maximum torque required to twist the core during the stranding process and the cross section of the metallic conductor. Experiments show that conductors made of copper need the maximum torque. Copper Conductors are always multi wired types because single wired ones would be much too stiff for stranding.

In the case of the aluminum cores, the figure shows, that single wired conductors require more torque to strand them as the multi wired ones. In general single wired conductors are stiffer than multi wired conductors (same material and the same cross section assumed).

Out of these results of the experiments the maximum torque of the 95 mm^2 copper-conductor is used for the design and optimization of the stranding head (toothed belts, drive motor...). See figure 5.

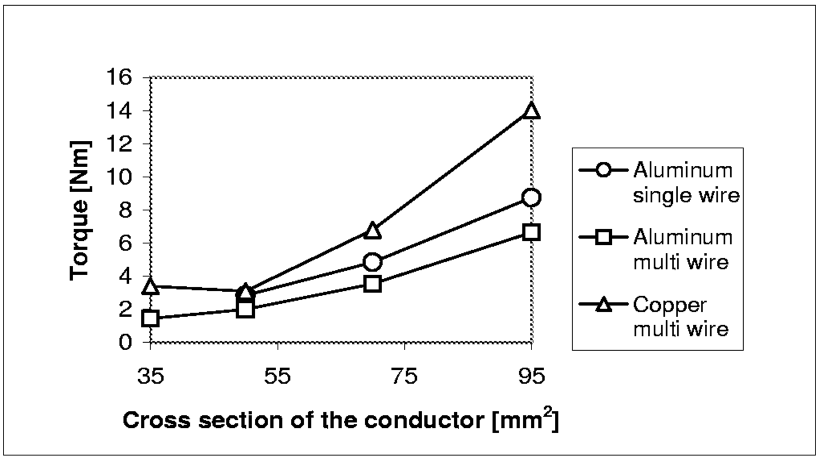

Figure 5. Correlation between measured torque and the cross section of the conductor

4.3.2 Area of hysteresis loops

Illustration 6 shows the connection between the hysteresis area and the cross-sectional area of the metallic conductor. One can note from this diagram that the area surrounded by the hysteresis line are for instance identical for multi wired conductors (aluminum and copper). Only the unifilar aluminum conductor shows much larger hysteresis area and shows stronger plastic material behavior as the multi wired conductors. For the lay storage design, in particular for the determination of the lay storage length, the conductor with the biggest area (aluminum conductor, single wired with 95mm^2 cross section) is used.

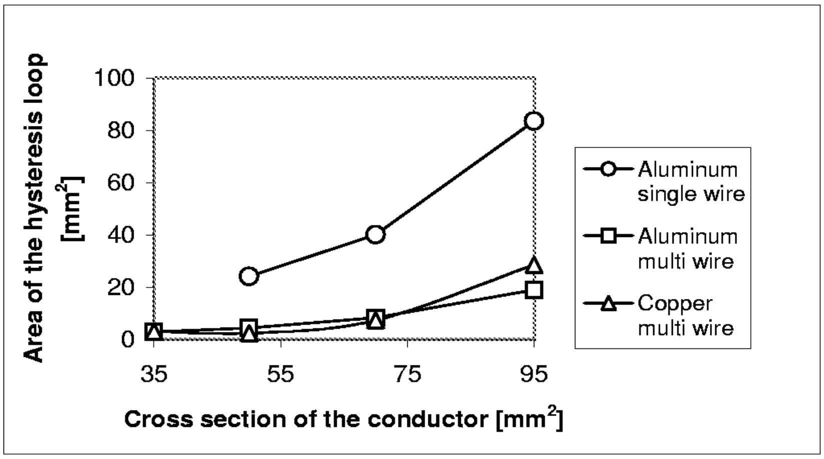

Figure 6. Correlation between the area of the hysteresis loop and the cross section of the conductor

5 SUMMARY

By means of measurement of the hysteresis loops of the relevant cable wires, both parameters, evaluated in test bed experiments (maximum stranding torque M_{max}, maximum deformation work respectively the area of the hysteresis loop A_H) are necessary for the optimization of the SZ-stranding machine. M_{max} could in this case directly be read out from the hysteresis diagram and is used for the design of the entire stranding head. A_H is computer-assisted calculated out of the measurement points and used for the design of the lay storage (lay storage length). Hardening influences while passing through the hysteresis loop many times could not be found in the experiment, therefore they could remain unconsidered during the design process.

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