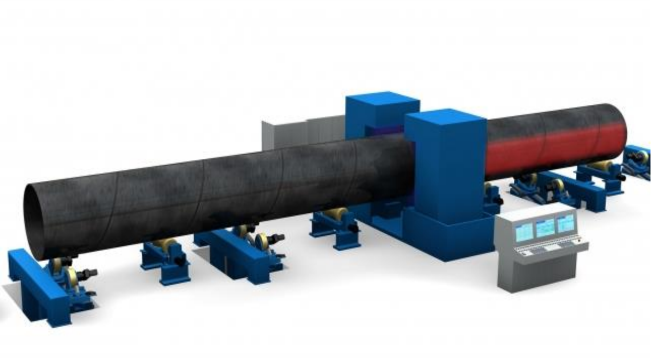
Demagnetization of large surface objects before welding

Demagnetization of construction pipes

Demagnetization of a steel box girder



Demagnetizer for large pipes (concept)
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Introduction

This white paper provides an overview over known demagnetization methods (also known as degaussing) in the field of welding processes. These methods are however limited in demagnetizing large surface objects. For such cases, a new method is introduced for complete demagnetization of large surface steel objects before final assembly.

Some examples of large surface steel objects:

- Construction pipes and pipelines
- Ship construction modules
- Offshore modules
- Pressure vessels and tanks
- Large girders and trusses
- Steel panels
- Heat exchangers

Steel objects may become magnetized during manufacturing and handling processes. Procedures such as magnetic crack detection, welding-, forming- and plasma cutting are usually also magnetizing steel components. Induced magnetic fields caused by the magnetic field of earth may concentrate in large ferromagnetic objects and cause a permanent magnetization of the steel. Furthermore steel is magnetized by the use of electromagnetic- or permanent magnetic lifters (according to reference [1]).

High strength structural steels tend to magnetize more than those of lower strength, which is due to the relatively high coercivity of fine grained steel.

High amounts of nickel (for example 9% Ni steel used for LNG tanks) enhance the magnetization susceptibility [3]. Local material structural changes lead to raised magnetic coercive forces according to experience. This means that local zones or entire surface portions of the steel may exhibit an intensified residual magnetism. The residual magnetism arises at the transition from the steel to the air. It can be measured as magnetic field strength in that place .

The field strength is greatly increased on projecting edges and narrowings due to flux concentration effects. The residual magnetism can also proceed in closed magnetic circuits in the material, as it's often encountered on submerged arc welded tubes. The magnetic field runs in the closed circumference of the tube and is recognizable as a magnetic stray field strength at irregular shapes of pipe ends only.

Intensified residual magnetism brings disadvantages in further processing and in terms of the lifetime of the final product.

The following procedures are affected in the further processing:

- Arc welding (mainly DC, at higher magnetic fields also AC)
- NDT (eddy current and sometimes X-Ray)
- Coating (residual dirt problems because of magnetic particle sticking)

In terms of lifetime:

- Studies show an increased susceptibility to hydrogen induced corrosion [6, 7]

The art of dealing with interfering magnetic fields during welding process

The most common problem with excessive residual magnetism on steel objects is the disturbance of welding processes. The phenomenon is known as "magnetic arc blow". The total magnetic field in the joint preparation causes a deflection of the arc by the Lorentz force [4].

Notations used for magnetic fields and their explanations:

Ambient field $\boldsymbol{H_a}$:	The ambient field induces in the steel object a magnetic flux. The ambient magnetic field is usually the magnetic field of earth.
Residual magnetism $\boldsymbol{B_r}$:	Magnetic remanence present in the steel.
Welding current field $\boldsymbol{H_w}$:	Field arising by welding current (returning ground current).
Reversing field $\boldsymbol{H_{rev}}$:	Adjustable magnetic field which is used to cancel the field in the joint preparation. It's generated by a coil and a DC power source.
Total field $\boldsymbol{H_{tot}}$:	The magnetic flux inside the material and external magnetic fields cause a total field in the joint preparation. The total field is the sum of the individual magnetic fields (for magnetic fields the principle of superposition applies).

The deflection of the arc is prevented by the substantial reduction of the total field in the joint preparation. The magnetic flux present in the steel plays no direct role in terms of magnetic arc blow.

When welding technology measures come to a limit, the following magnetic methods are used to reduce the total field in the joint preparation:

Reversing field: The total field is neutralized by the application of a reversing field. *Knockdown:* A reversing field is applied in order to eliminate recurring of the total field after removal of the reversing field. *Demagnetization:* The material is demagnetized by a reversing and decreasing magnetic field.

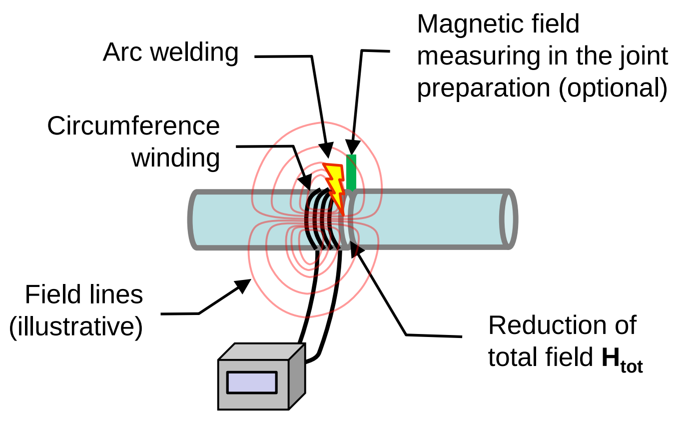
Equipment		**Reversing Field**	**Knockdown**	**Demagnetization**
Power source	Welding rectifier or DC power source	Yes	Yes	No
	Reversable current source	Yes	Yes	Yes
	High power sine AC current source	No	No	Yes
Coil	Wrapped coil by flexible cables	Yes	Yes	Yes
	Bobbins	Yes	Yes	Yes
	Clam coil	Yes	Yes	Limited

(Stationary demagnetizing systems are not discussed here).

Examples of Reversing Field, Knockdown and Demagnetization methods

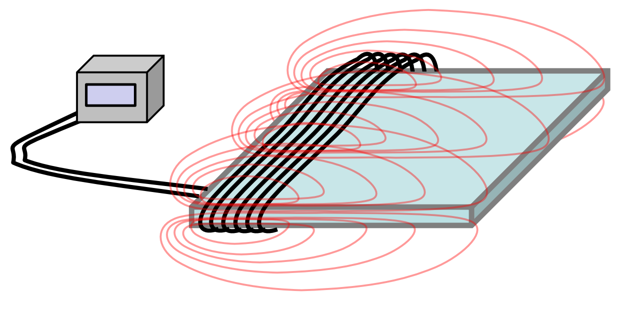
Cables wrapped around the object close to the weld: ***circumference winding***

- Reversing Field, Knockdown or Demagnetization method applicable.
- The magnetic effect is limited to the vicinity of the coil (applies to all examples).
- Substantial winding time expenses.
- When using clam coils or bobbins reduced winding effort.



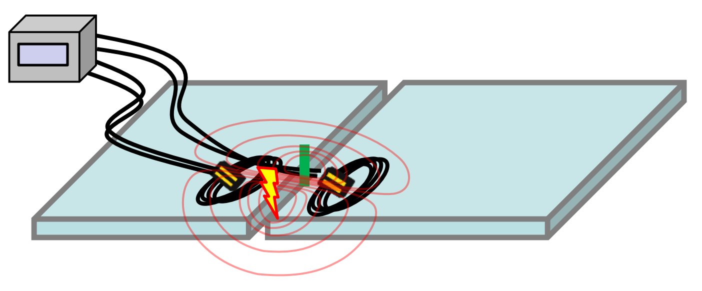
Circumference winding at the end of a plate:

- Knockdown or Demagnetization method applicable.
- Only feasible with flexible cable coils, substantial winding time expenses.
- Demagnetization of the entire object needs repositioning- and a new winding of the coil.



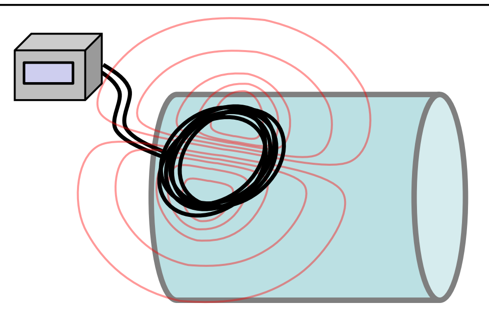
Cable coil placed on the surface of the object: ***Lay on winding***

- Reversing Field, Knockdown or Demagnetization method applicable.
- Coils must be repositioned but don‘t need to be re-wound.



Lay on winding at the end of a pipe:

- Knockdown or Demagnetization method applicable.
- Demagnetization of the entire object needs repositioning but no re-winding of the coil.

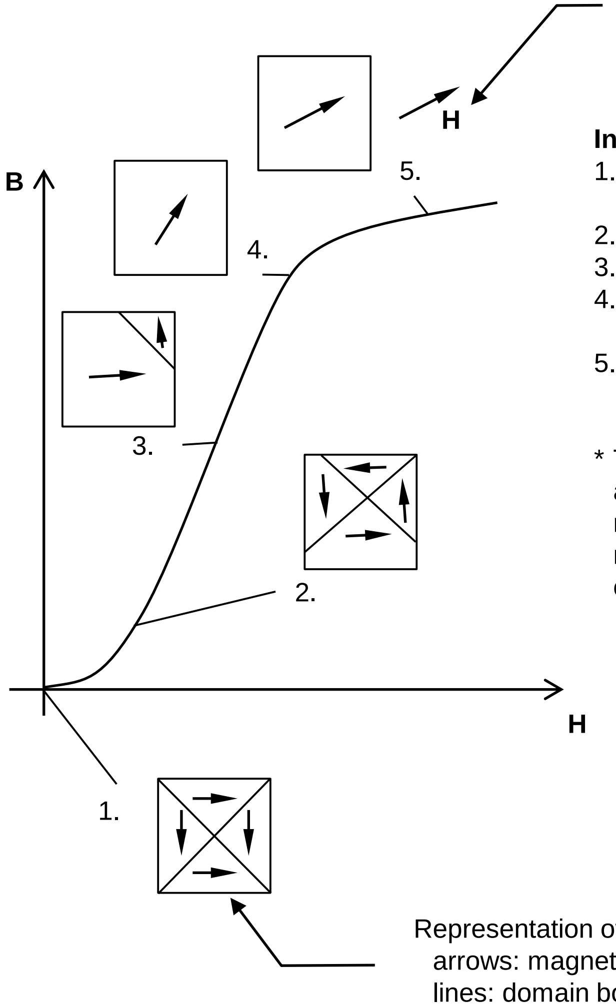


The magnetic state of the material

The magnetic state (domain structure) in the ferromagnetic material can be illustrated by looking at the initial magnetization curve. This curve describes the magnetization processes in the material as a function of applied field **H**.

The magnetic domains are always magnetized up to saturation and bounded by walls (Bloch walls). The magnetization direction of the adjacent domains rotates in the domain wall. By intensifying field strength **H**, the magnetization direction of the domains increasingly turns in the direction of the external field **H**. The Bloch walls disappear successively with more domains aligned in the same direction. In case of complete saturation exists only one large domain.

H: Sum of all magnetic fields acting from the outside on the material



Initial magnetization curve B(H) [8]

1. Non-magnetic state* with closed loop structure (no magnetic flux leakage).
2. Reversible wall displacements.
3. Irreversible wall displacements.
4. Wall displacement process is finished, beginning of reversible rotation processes.
5. Further increase in the flux density **B** with running into saturation only by rotation of the polarization process.

* This state is achieved by annealing process or by alternating field demagnetization. The material is returned from the magnetic saturation again into the non-magnetic state due to a high number of polarity reversals of decreasing amplitude .

Representation of the magnetic domain structure:
arrows: magnetization direction of the domain
lines: domain boundary = Bloch wall
(size of a magnetic domain: approximately 10µm up to 1mm)

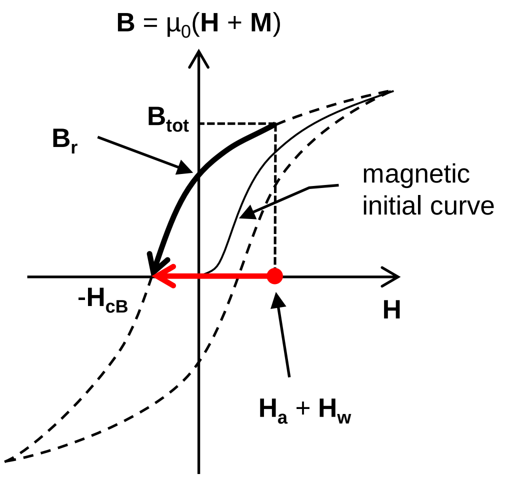
The Reversing Field, Knockdown and Demagnetization procedures described below reference to the initial magnetization curve.

Description of the procedures

1) Reversing Field

The disturbing magnetic fields in the joint preparation are tried to be neutralized by Reversing Fields of a specific amplitude. A direct current is adjusted at the power source which generates the Reversing Field in the coil. This Reversing Field superimposes with the disturbing total field in the joint preparation. In the optimum case the total field may largely be neutralized when applying the correct coil current.

The following happens in the material:



Hysteresis curve

– Notes on $\mathbf{H_{rev}}$, $\mathbf{H_a}$, $\mathbf{H_w}$, $\mathbf{B_r}$ according to page 3.
– Coercive field of the magnetic flux density: $\mathbf{H_{cB}}$
– Reversing Field $\mathbf{H_{rev}} = \mathbf{H_a} + \mathbf{H_w} + \mathbf{H_{cB}}$. The total flux $\mathbf{B_{tot}}$ is pushed in the vicinity of zero.
– The Reversing Field stays turned on during the welding process.
– The total flux $\mathbf{B_{tot}}$ rebuilds after removal of the Reversing Field.

Joint preparation

– The total field in the joint preparation results as a superposition of the flux leakage* and the surrounding fields (not shown in the graph).

***** Emerging field lines from the steel are called flux leakage.

Advantages

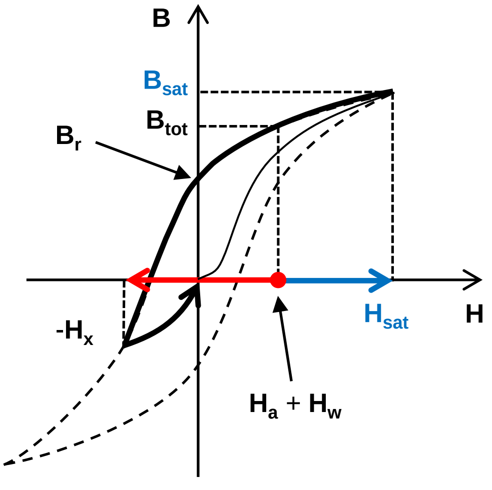
- Feasible by conventional welding equipment. What is needed is an adjustable welding rectifier and a welding cable of sufficient length.
- The method is capable of neutralizing theoretically any kind of disturbing total fields.

Disadvantages

- It's difficult to obtain the right Reversing Field without the use of magnetic field measurement in the joint preparation. This often leads to a "trial and error" method with a correspondingly low productivity and quality.
- The Reversing Field must be readjusted several times in the case of multipole fields in the joint preparation.
- Winding of a coil can't be performed in some cases.
- Modern welding machines are based on inverter technology using pulsed welding current. The Reversing Field method can't be easily implemented with such systems.
- The material is not demagnetized (point 3 in the initial magnetization curve, see page 5).

2) Knockdown

As a first step, the wound steel portion is magnetized directionally as possible to magnetic saturation. Multipole fields are rectified prior to the Knockdown through that. The second step is to apply a defined Reversing Field in a way that after removal of the Reversing Field, the total field drops to zero in the joint preparation [9].



Hysteresis curve

– Notes on H_{rev}, H_a, H_w, B_r according to page 3.
– H_x: field, wherein the flux **B** becomes zero after removal of H_{rev}.
– The material is magnetized first to saturation (B_{sat}, H_{sat}).
– Setting of Reversing Field $H_{rev} = H_a + H_w^* + H_x$.
– The Reversing Field is switched off during the welding process.
– The total flux B_{tot} remains some time near zero after removal of the Reversing Field.

* In practice, the welding current field H_w is often omitted when determining the Reversing Field.

Joint preparation

– The total field in the joint preparation results as a superposition of the flux leakage* and the surrounding fields (not shown in the graph).

Advantages

- The Reversing Field coil can be removed after the Knockdown.
- The welds can be prepared in advance for the welding process (for example by use of demagnetizing teams).

Disadvantages

- After a certain time the magnetization in the steel arises again. This happens because steel zones still contain residual magnetism that is slowly propagating towards the knockdown zone (typically after about 1-2 hours).
- This method alone is not able to remove the total field in case of strong ambient fields. The use of the Reversing Field method is additionally required.
- The material is not demagnetized (point 3 in the initial magnetization curve, see page 5).

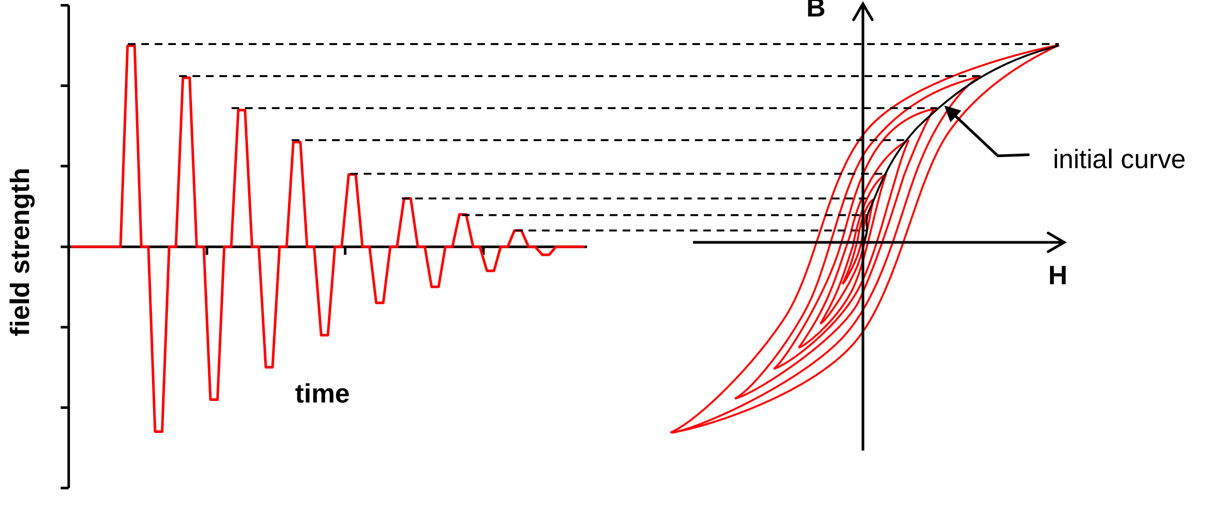
3) Demagnetization (Degaussing)

This method is based on an decaying alternating magnetic field produced by a coil. The power source generates therefore reversing DC (or AC) currents with decreasing amplitude. The process causes the demagnetization of the material by the successive reduction of the hysteresis loop. The materiall is first fully magnetized (rectifying of all the magnetic domains). Thereafter, reversing the polarity of the magnetic zones and reducing the field amplitude leads to a statistical distribution of the domain magnetization direction [10].

The quality of the process depends on the following parameters:

- Maximum field strength (for magnetic saturation of the material).
- Frequency of the pole reversals (low frequency for more penetration depth).
- Extension of the effective magnetic field (high effective range for covering large surfaces).
- Homogeneity of the effective range (uniformity of the field within the effective range).
- Decay precision (low decrement of the amplitude [10] and high field symmetry precision).

3.1) Demagnetization by reversing DC field (down cycling)



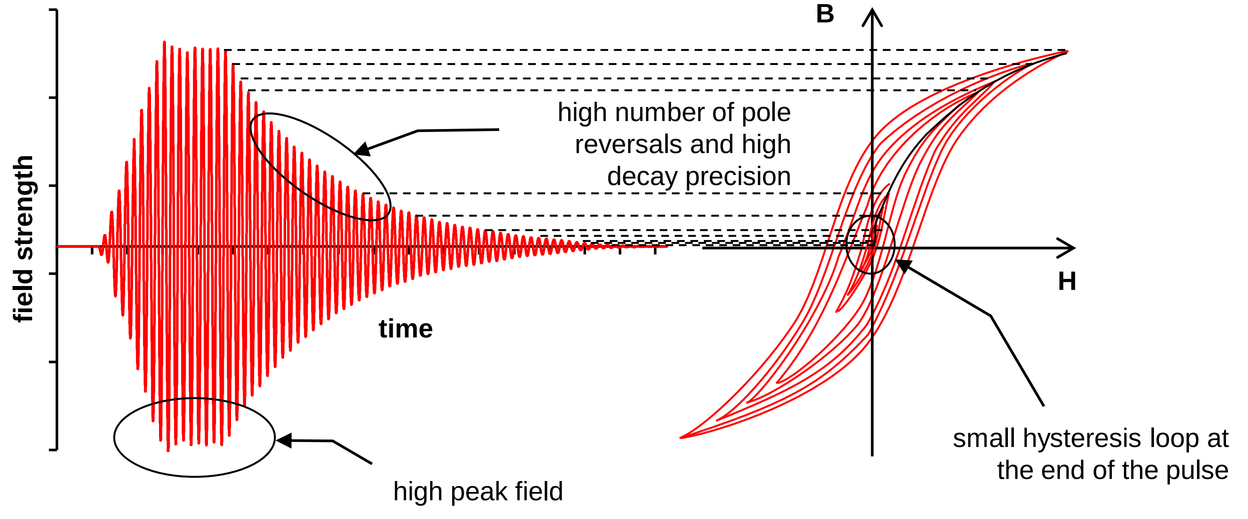
Advantages

- The material is demagnetized (state 1 to 3 in the initial magnetization curve, see page 5).
- Requires no adjustment at the power source. The process is triggered by pushing a button.

Disadvantages

- Relatively long duration of the demagnetizing cycle (approx 30s to 3min, depending on the equipment).
- The long cycle time results in a relatively high current duty cycle. This leads to a substantial heating of the conductors and makes it impossible to generate high peak field strengths without advanced cooling measures of the coil.
- The entire demagnetization of large surface objects becomes very time consuming.
- The magnetism can not be eliminated or reduced sufficiently in any case. Possible reasons are insufficient demagnetization performance or the persistence of induced magnetic fields of high intensity.

3.2) Demagnetization by High Intensity Sine Pulse



The following pulse parameters were identified in practical experiments and are preferably used for demagnetization of large surface steel objects (up to ~60mm wall thickness):

- High field strength (about 50...100kA/m) for reversing hard magnetic zones and to increase the penetration depth.
- Demagnetization frequency approximately between 5Hz and 20Hz.
- Pulse duration 6...20s, depending on the demagnetization frequency.
- Coil with sufficiently large effective range (diameter about 600...1'000 mm). This is needed to interrupt closed magnetic circuits inside the material successfully and thus to prevent shifting of magnetism from one side to the other.
- Sine wave with high decay precision. This enables an optimal distribution of the magnetic domain magnetization direction within the material.

Advantages

- The process is fast, so it is suitable for pulse demagnetization of large steel surfaces.
- The material is optimally demagnetized (state 1 in the initial magnetization curve, see page 5).
- Requires no adjustment at the power source. Pulse triggered by pushing a button, easy to use.

Disadvantages

- The magnetism can not be eliminated or reduced sufficiently in any case (identical reasons as in the previous method 3.1)).
- The method requires a higher power electrical mains connection. When used in the field, a power generator with enough peak current power must be used .

Demagnetization of large surface subcomponents prior to assembly

full subcomponent demagnetization → transport → assembly → welding

This method has already been used in the past, but often with limited success. The reasons for this are described with insufficient effect of the demagnetization or with the too cumbersome and time consuming implementation [1, 5].

Maurer Magnetic AG has developed a new demagnetization procedure for subcomponents by use of the above described *High Intensity Sine Pulse Demagnetization*. The procedure has been successfully used several times. It is protected by several patents.

The procedure eliminates the residual magnetism of the entire subcomponent.

However this will not prevent that external fields continue to induce magnetic fluxes. The flux density is dependent on material, geometry and field strength of the applied field. In extreme cases, the induced fluxes may still cause arc blow despite previous complete demagnetization of the subcomponents.

Furthermore, it is known that DC or hybrid AC/DC welding processes have the potential to magnetize steel again [1]. In exceptional cases the demagnetization of the subcomponents alone is not enough. Sensitive welding processes must still be assisted with the previously described Reversing Field method 1).

Developments in the field of welding technology (AC methods, like for example G-FCAW-AC or tandem Wire DC/AC) increasingly lead to more stable arcs. This enables stable welding process even at intensified magnetic field strengths [2].

Seen holistically, the method described herein offers advantages with respect to subsequent welding processes and also non destructive testing with eddy current or X-Ray technologies. Furthermore it reduces the susceptibility to magnetocorrosion [6, 7]. These benefits are included in the final product by carefully avoiding a subsequent magnetization of the subcomponents.

Equipment

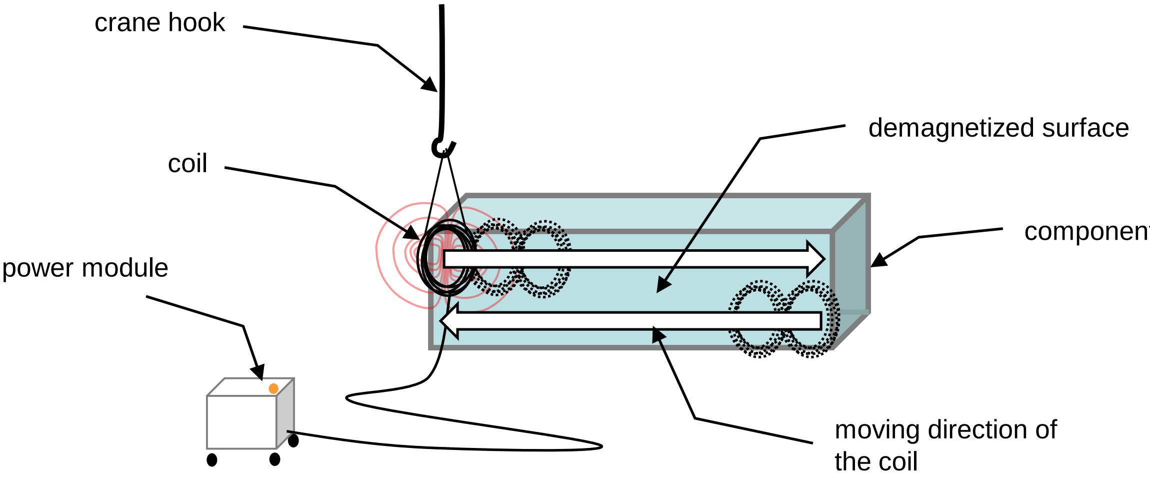
The demagnetizing machine consists of a power module type MM DM /-P /-PC. The coil is wound from two to three flexible demagnetizing cables. Mainly the cable type K8/10-30 with a length of 30m is used. This cable contains 8 conductors and it can be interconnected repeatedly. Preferably 3 cables are employed with a total conductor length of about 3 x 30m x 8 = 720m. This cable length is wound into a coil of about 1m in diameter.

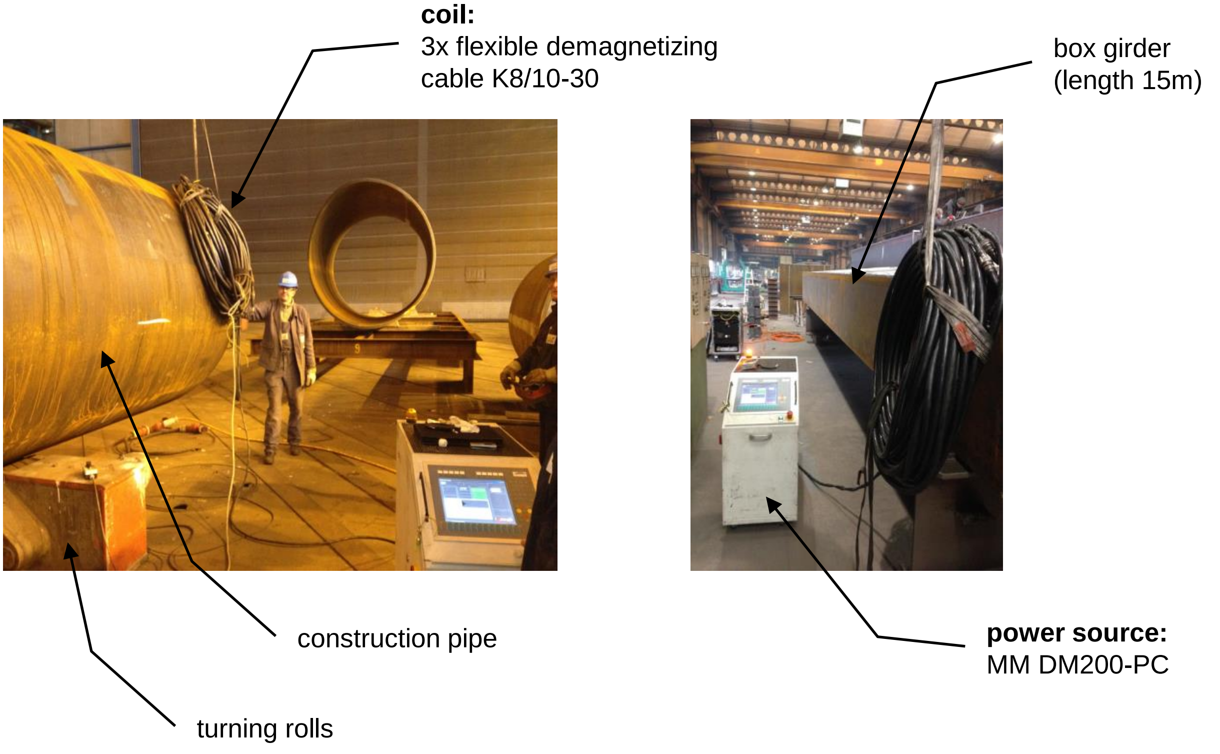
The maximum power generated by a power module MM DM200 connected to 3 cables is of about 60kW. This high power (about 30 times higher than in the previous methods) is only briefly consumed while a few hundred milliseconds during the pulse process at peak power. The average power is about 3 to 6% of the maximum power when pulsing with a rate 1-2 pulses per minute. This reduces the thermal load and thus the heating of the coil. The short term maximum power must be however provided from the mains or by a power generator. A standard three phase mains connection 3x380...480VAC 50/60Hz with 63A is sufficient (temporary overload of up to 200A is located within the standard fuse characteristics).

The high field strength allows the demagnetization with relatively high frequencies (5...20Hz) and still sufficient penetration depth into the material. The high frequency in turn allows a short pulse duration with a high number of pole reversals.

Demagnetization procedure:

The demagnetization of the whole object is done by demagnetizing all surface subareas. The surface subarea is overlapped by the coil an demagnetized entirely by one pulse (duration ~6...20s). Between the pulses the coil is moved to the next subarea. During the pulse the coil remains stationary.





Time requirements

The multiple use of the process has confirmed a high productivity. Crucial for quick progress is essentially the moving of the coil between the demagnetizing pulses. The coil handling with a crane has proven to be efficient and for demagnetization of large pipes, the use of turning rolls has shown to be advantageous. The optimum handling is generally dependent on the present object.

Demagnetization of 20 construction pipes DxL 2'500x7'000, wall thickness 20 and 40mm, X52 steel:

Used coil diameter ~1m. Number of pulses / tube: 7 x 7 = 49 pulses of 10s duration each. By use of turning rolls, an average time of 30s was needed for the handling of the coil between the pulses. The overall demagnetization time came to: t_d = 49 x 10s + 49 x 30s = 1'960s = 32,66min.

20 construction pipes were demagnetized within 20 x 32,66min = 653,2min = 11h on the construction site (loading and unloading of the pipes not counted).

The period between the demagnetization, the transport and the final welding was several days in this job.

Demagnetization of 2 box girders LxHxW 15'000x2'300x1'000mm, wall thickness 20mm, S355M steel:

Used coil diameter ~1m. Number of pulses / box girder: 2 x 2 x 15 = 60 pulses. The duration of each pulse is 10s, the total time came to 60 x 10s = 600s. The handling of the coil between the pulses has taken about 40s on average, 60 x 40s = 2'400s. The overall demagnetization time came to: t_d = 600s + 2'400s = 3'000s = 50min (moving of the demagnetization equipment on site not counted).

The period between the demagnetization, the transport and the final welding was several weeks in this job.

In both examples no re-magnetization of the objects has been observed between the demagnetization process and the final assembly.

Benefits

- The process results in a substantial reduction or elimination of the residual magnetism in the entire ferromagnetic object.
- The complete demagnetization of the ferromagnetic object has a beneficial effect on the phenomenon of hydrogen induced corrosion.
- A re-magnetization is not possible without exposure to strong magnetic fields, high deformation grades or not appropriate handling.
- It was observed that the residual magnetism level after demagnetization is even further decreasing by itself (especially after transport with slight shocks or vibrations).
- The demagnetization increases productivity and quality of subsequent processes such as welding, nondestructive testing and coating.
- The process is easy to use and the personnel doesn't require special skills.
- The demagnetization can be implemented at sub suppliers what leads to consistently stable quality steel prefabricates.
- The process can be adopted for automated and continuous use.

Disadvantages

- Ambient magnetic fields induce magnetic fields in the objects. The spots with the highest induced magnetic fields range typically between 2... 10 Gauss after demagnetization. These spots usually appear at projecting edges on each object. These induced residual fields can only be completely eliminated by the above described method 1).

Conclusion

The use of high alloy, fine grained steels, the globalized supply chain, steel manufacturers with unstable quality levels and finally long transport routes with frequent reloading effect on average an accumulation of problems caused by residual magnetism.

Technological advances increasingly lead to welding processes resistant to magnetic interference. Nonetheless, disturbances due to magnetic fields may occur with sensitive welding processes and impede the fulfillment of high quality requirements. Disturbing residual magnetic fields delay the production, generate high costs and reduce the quality and durability of the final product.

The complete demagnetization of the prefabricated subcomponents prior to assembly provides a consistent quality of the material on site and minimizes unnecessary process disruptions in the construction of the final product.

The approach presented in this paper can be implemented manually or automatically at sub suppliers or at the final construction site. The *Sine Field Pulse Demagnetization* with massively higher performance is significantly different from the methods used to date. It's characterized by simplicity, high productivity and process reliability.

If required, the assembled final product can be completely demagnetized by the same method again. On the one hand the residual magnetism is removed in the material and on the other hand, the magnetic stray field (permanent magnetic signature) is thereby also substantially reduced.

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