ELECTRICAL DISCHARGE TEXTURING (EDT) – INCREASE OF ROLL SURFACE QUALITY BY USE OF LINEAR MOTORS IN A CRM ROLLSHOP

BY

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SYNOPSIS:

In the field of electrical discharge machining (EDM) resp. electrical discharge texturing (EDT), Kleinknecht has a long track record of proven experience. For 40 years Kleinknecht has been developing controls and generator technology for EDM and EDT machines.

Today, more than 60 EDT machines worldwide are equipped with electrical controls and generators (firing units). In the EDT process, which involves thousands of ignitions per second, the work roll surface is roughened. This defined roll topography is then transferred during the rolling process onto the strip. These strips are being used for sheet metal in automobile construction or to produce white goods. Since 2010 Kleinknecht has been a successful manufacturer of complete EDT machines. The innovative concept of the Kleinknecht EDT machine eradicates all the known weaknesses of traditional machines.

This paper shows, by means of a practical test based on a step response diagram, how the use of a linear motors will increase the roll surface quality and reduce the machining time.

Keywords: EDT, Discharge, Sparking, Firing, Texturing, Roll, Surface, Topography, Generator, Linear Motor, Innovation, Cold Rolling, Automotive, White Goods, Rollshop, EDM, WR, UDS, MES-T, CRM

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1. INTRODUCTION

Over the past 35 years roll surface treatment has gone through various phases. Different philosophies have been applied, all of which have delivered - more or less satisfactory - results at the time. The major difference between the different types of production, such as

- Electrical Discharge Texturing (EDT),
- Electrochemical Coating,
- Laser Texturing (LT),
- Electron Beam Texturing (EBT),
- Shot blasting (SB),

is surface quality and price per roll treated. Kleinknecht has been a player in the field of Electrical Discharge Texturing from as early as 1971. Kleinknecht had started to develop and produce generators (firing unit creating a spark) for EDM machines. On this basis the first European EDT machine was equipped with Kleinknecht generators in 1985 and has been operating ever since. The very stable operation of the finely tuned Kleinknecht generator led to further 60 EDT machines – all equipped with these generators. In total, Kleinknecht has supplied more than 3,000 generators to date.

With the increase of technological know-how because of the on-site feedback received, Kleinknecht decided to further improve the roll surface treatment technology in 2008. This was kicked off by a detailed market survey and the question: “Which is the best value for money roll surface treatment?” This question had clearly been answered in favor of the EDT process, because

- Shot blasting is too poor for high quality surface demands (especially regarding roll-to-roll repeatability of surface roughness),
- EBT was too difficult to operate under rollshop conditions, and has thus been discontinued throughout the last decade,
- Electrochemical Coating, compared to the EDT process, is very expensive,
- Laser texturing cannot guarantee a 100% machined surface (open spots with ground surface will remain).

To cut a long story short: Kleinknecht found themselves confirmed in their decision to continue down the EDT road they had followed for more than 40 years. Based on the EDT know-how, Kleinknecht had decided to design and build a completely new EDT machine in 2009. The most important factor was to close the gap with their competition in terms of mechanical engineering competence. Again, a technical survey at the leading EDT machine operators had been launched, to find the weak points of the existing and conventional EDT machine designs.

The main target in building a new generation of EDT machine was to significantly improve the texturing quality in a most stable texturing environment. At the same time, the price level of a new machine and textured roll had to be the same – or even better – at a lower price level than previously achieved.

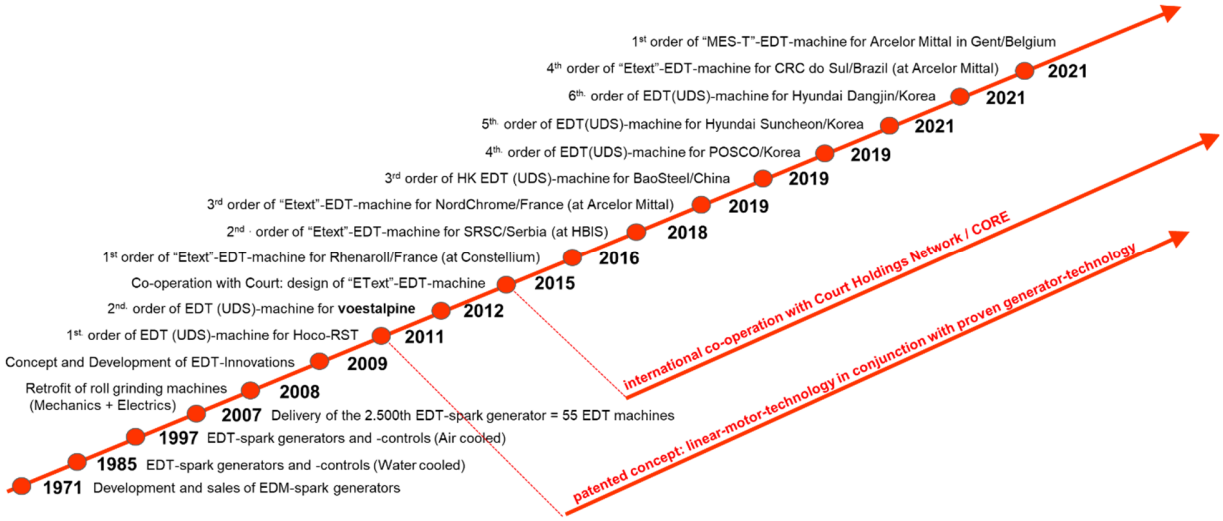

Illustration 1: History of Kleinknecht EDM/EDT activities

1.1 EDT Quality Parameters

The quality parameters of a roll surface created by EDT depend on several mechanical and electrical characteristics. Besides a properly ground roll the main pre-conditions for a smooth texturing process are mechanical strength and machine stability, constant texturing environment and powerful generators. These issues are well known in the roll treatment business. What is new and innovative to the industry, is the approach Kleinknecht has utilized to secure all these demands in the live texturing environment of an EDT machine. The various innovations are specified in the following paragraphs.

1.2 Innovation in EDT for Rolls

In day-to-day manufacturing business we all have encountered problems – either mechanical or electrical – which have definite source. Sometimes it may be possible to compensate a lack of mechanical performance with smart automation features, or vice-versa. These 'work-around' solutions might help at the time but are certainly a non-starter for a new era of high-end EDT performance machines. The basis of high-level

surface texturing is mechanical strength, incl. smart design engineering solutions, as well as the utilization of innovative key components on the automation side, such as direct drive technology and a high-end fine-tuned generator.

2. MECHANICAL INNOVATIONS AND MACHINE IMPROVEMENTS

This chapter will describe the mechanical innovations in EDT machines which build the basis for the successful implementation of new automation features. For a better understanding of the following mechanical description, please find some picture of an EDT machine below, which comprises the following innovations:

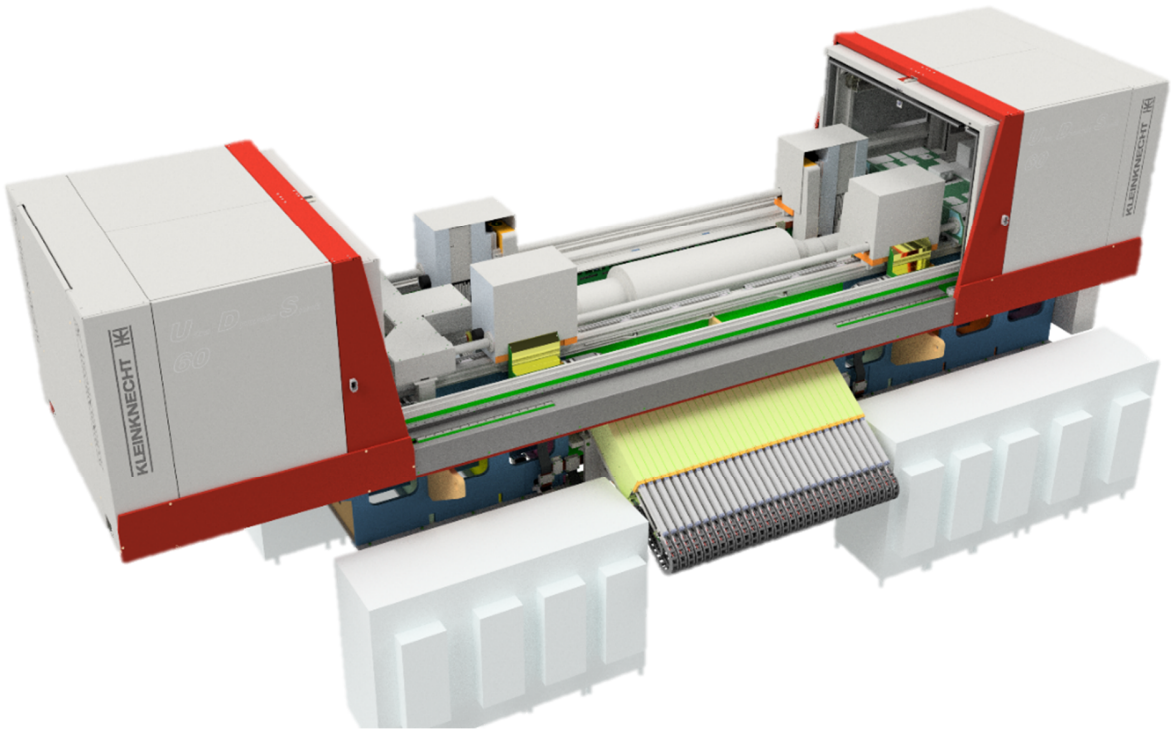

Illustration 2: Total view of EDT machine, Type “Ultra Dynamic Spark” (UDS)

2.1 Torque Motor

The mechanical machine stability needs to provide absolutely smooth roll movement throughout. Turning the roll and oscillating the roll must be free of any mechanical

disturbance, i.e., no gearbox and no clutch should be involved in the mechanical layout. The usual approach with an AC squirrel cage induction motor requires a gearbox, to achieve the low revolutions for the process. The state-of-the-art technology of direct drive motors provides the perfect solution for this demand: A torque motor used in the range of 0 to 70 rpm provides its nominal torque over the complete range, even from as low as 1 rpm.

2.2 Outside Guide Rails

To achieve a clean and empty texturing tub (machine tank for dielectric oil), the machine tub inside needs to be free of any cable chains, guide rails or ball screw spindles. All these components will suffer mechanical wear due to the particles and residuals from the texturing process in the dielectric bath. The repair or exchange of these components will regularly cause machine downtime and create unnecessary spare part costs.

2.3 Self-Cleaning Tub

At the same time, operators do not always pay sufficient attention to cleaning. In the case of an EDT process, the mud and sludge with its copper and carbon particles remaining in the machine, could create short circuits between the live parts of the texturing heads or electrodes. As a result, the texturing process will be deficient, and will have to be aborted.

A machine concept with guide rails, cable chains and spindles all of which located outside the dielectric bath will provide a self-cleaning tub with no wear and tear inside the machine tub whatsoever. An innovative nozzle system will even clean the tub and the texturing heads after each texturing process.

2.4 Electrode Positioning

There are two options in positioning the electrodes alongside the roll barrel:

- at a fixed position, i.e., the roll will oscillate
- on a movable support, i.e., the set of electrodes travels alongside the roll

The innovative electrode drive concept comprises a linear motor system, which can be controlled and adjusted extremely fast to high accuracy ± 1µm. This is even more impressive considering this accuracy can be achieved at any position of the electrode travel. This is a major advantage compared to the controls of a preloaded ball screw

spindle. The performance of a ball screw drive suffers from wear of spindle resp. nut and is also vulnerable to temperature deviation (expand and contract of spindle).

2.5 Smart Drive Concept Enables Reduction of Number of Drives

Besides the individual electrode adjustment, a conventional EDT machine comprises the following number of electric and hydraulic drives:

- 1. roll rotation (electric drive)
- 2. roll oscillation (electric drive)
- 3. steady rest 1 positioning (hydraulic drive on conventional machines)
- 4. steady rest 1 lower/raise (hydraulic drive on conventional machines)
- 5. steady rest 2 positioning (hydraulic drive on conventional machines)
- 6. steady rest 2 lower/raise (hydraulic drive on conventional machines)
- 7. tailstock positioning (hydraulic drive on conventional machines)

The Kleinknecht drive system utilizes a smart centralized positioning drive combined with intelligent clamping units on each of the main machine units. Instead of seven (7) drives - most of which hydraulic - only four (4) electric variable frequency-controlled drives need to be utilized:

- 1. roll rotation (electric drive)
- 2. central positioning drive (electric drive) for
    - 2.1 roll oscillation
    - 2.2 steady rest 1 positioning
    - 2.3 steady rest 2 positioning
    - 2.4 tailstock positioning
- 3. steady rest 1 lower/raise (master/slave electric drive)
- 4. steady rest 2 lower/raise (master/slave electric drive)

Regarding the number of drives, the maintenance and spare parts costs compared to a conventional machine are significantly lower.

2.6 No Hydraulic Units in the Machine Tub

Even more important is the fact that the new design would not cause any environmental or health problems, which could occur on conventional EDT machines due to the leakage of hydraulic oil into the dielectric bath. If hydraulic oil mixes with dielectric oil, potential toxic benzene derivates arise out of the cracked chemical structure during the texturing process. According to the American Petroleum Institute (API) ‘the only safe

concentration of benzene is zero'. This statement was taken seriously in the mechanical design of the innovative Kleinknecht EDT machine, i.e., under no circumstances will the contamination of the dielectric bath with hydraulic oil be possible.

2.7 Widest Possible Range of Work Rolls

The machine concept allows a wide variety of roll types – the widest range in its class. The flexible positioning of the steady rests offers the ability to take rolls with a short barrel length of approx. 100mm up to a maximum barrel length of 2,400mm. The new EDT machine can texture short rolls by utilizing just one electrode to a maximum of 60 electrodes, without any mechanical or electrical options or upgrades.

2.8 Soft Facts

The texturing process needs to adhere to strict health and safety demands. To meet the latest European and North American health & safety regulations, this can only be achieved with a completely covered machine. To allow best possible view into the machine during texturing the machine cover has been designed with large windows, and a sophisticated LED lighting system.

Further, the tub will fully rinse after texturing. Due to the machine design incorporating an innovative nozzle system the tub is self-cleaning, i.e., no major residuals and slurry will stay behind to potentially cause quality issues. As a result of self-cleaning, maintenance will significantly be reduced.

3. TEXTURING INNOVATIONS AND IMPROVEMENTS

3.1 Stability of Texturing Environment

This issue has been the subject of the highest level of innovation. Only when the texturing process runs in a highly reproducible way, the maximum quality result can be achieved. The various factors for creating a stable texturing environment might be well known to all the end users and operators of EDT machines. However, the Kleinknecht design has innovative answers to some of the technological questions and long-term demands. The machine performance during the texturing process mainly depends on the following parameters:

- most accurate and highly dynamic gap control
- constant electrode flushing pressure
- no contamination of the texturing bath with hydraulic oil
- constant quality of dielectric oil
- identical resistance on any side of the machine

The following paragraph will describe the Kleinknecht approach for securing the best possible solution of the above key parameters. The key factor in electrical discharge texturing – besides a sophisticated high-end generator – is the dynamic and most accurate control of the gap between the roll and the electrode. In the past, this gap control was carried out by servo-hydraulic cylinders and valves. The CONs of servo-hydraulics are slow speed, different control behavior at different piston positions, and potential pollution of dielectric oil with hydraulic oil in the case of leaks. Even the attempted use of ball-screw spindles for the electrode adjustment is much more likely to fail due to the very fast wear of the ball-screw system and the thousands of positioning movements during texturing of just one roll (not even considering the stiffness disadvantage, backlash and temperature dependence of a ball screw spindle).

To summarize: A very stable and free of wear answer to maximum precision, long lasting, dynamic, maintenance free and smooth electrode movement and perfect gap control is a linear motor design.

A Kleinknecht texturing unit with linear motor technology consists of a moving non-ferrous coil winding (primary part), the U-stator with facing permanent magnets (secondary part), the direct measuring system (linear glass scale), the clamped and moving pipe at which end the electrode head is connected.

In addition to the technical performance requirements stated above, the engineering solution of the linear motor unit had to fulfill another even higher demand: no influence between the linear motors. The compact machine design and the installation of up to 30 linear motor units in one row also had to avoid any disturbance caused by electrical noise. Under no circumstance a neighboring motor and/or its designated measuring system must be influenced by another drive. Rigorous endurance tests have led to the final design of the texturing unit being 100% free of any negative influence and disturbance from outside.

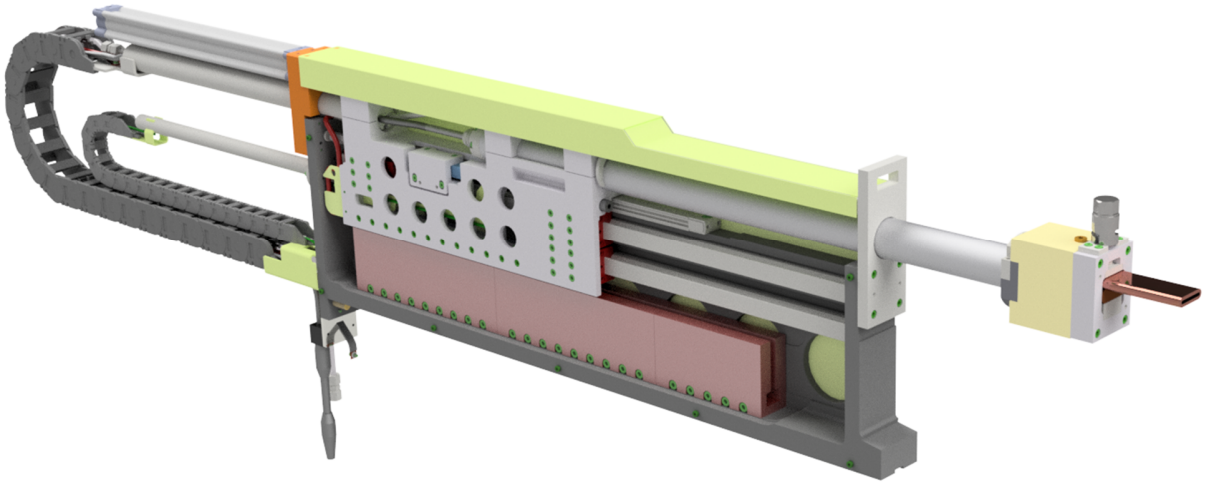

Illustration 3: Linear motor units (without cover)

The quality of the dielectric oil must be maintained for a constant texturing environment. Under no circumstances should it be possible to pollute the dielectric oil with other substances, such as hydraulic oil. As there are now no hydraulic cylinders or hydraulic motors inside the tub, it is virtually impossible for hydraulic oil to leak into the dielectric bath (see previous paragraph ‘No Hydraulic Units in the Machine Tub’).

A further influence on an evenly spread and perfect surface is the electrical impedance of the machine. The copper cables and busbars providing the electrical grounding system need to be designed symmetrically for each side of the machine. As a result, another potential source for bandings has been eradicated.

Over and above these issues, the spark generation has a great influence on the textured surface quality. The latest Kleinknecht generator comprises the following main features

- eight (8) modes of operation (Pulse if/ie, CAP pc/cc, +/- polarity)
- individual parameter selection for individual roll edge preparation
- ignition/spark verification

What is new in this respect is the individually selectable set of parameters for each of the generators. Initially this seems not to make any sense. Who wants to deliberately create a zebra pattern on the roll? The reason behind this feature is not the sequenced change of parameters for every other generator, but the deliberate change to a different roughness towards the edges of the barrel of specific rolls used for instance in strip lines.

3.2 Cycle Times / Machine Setup Times Reduction and Surface Quality Improvements

A unique multi-functional cart (MFC) can be applied to carry out various optional machine features, such as

- measuring the horizontal roll alignment
- wiper function to clean the roll after texturing (remove dielectric oil)
- in-line roughness measuring
- roll finishing devices

The MFC is moving on separate guide rails, independently from any cover movement. This, again, is a further innovation, as previous machine designs could only incorporate measuring equipment and/or roll finishing systems in the machine cover. The travel speed of the MFC at closed machine cover is up to 30 m/min (500 mm/sec.). The smart utilization of the above features can significantly reduce the overall cycle times for post-processes after actual texturing.

The texturing cycle times of some specific surface qualities are shorter than previous machine concepts. This is mainly due to the fast reaction time of the linear motors. The major benefit of fast response times, due to the high dynamic of the linear motors, can be achieved at very low surface qualities < 1.0 µm Ra. Utilizing the well-known actual Kleinknecht generator the texturing time is approx. 10% faster than on machines with servo-hydraulic electrode drives. The evaluation of the individual sparking (firing) as a joint effort of the dynamic linear motors in conjunction with the latest state-of-the-art generators results in less short-circuits and less misfires.

3.2 Traditional Ball Screw Drive vs. Kleinknecht's Patented Linear Motor Unit

Topic	**Ball Screw Drive**	**Linear Motor Unit**
Position control	1ms (in CNC)	directly in the drive in the speed control cycle = 250 µs → 4 times faster!
Position circle gain "Kv"	1m/min/mm	10m/min/mm → 10 times higher!
Max. speed:	500mm/min	5,000mm/min → 10 times faster!
Actual value processing	must be digitized and sent via the bus (1ms) to the CNC, where the position controller calculates new setpoints and sends them	directly in the drive-internal PLC (Bosch MLD) at a rate of 1ms and added as an additional speed setpoint in the position control loop.

	back to the drives via the bus (1ms). This means that a change in the gap voltage only becomes effective at least 3ms later than a setpoint change on the drive.	→ at least 3 times faster!
Position feedback	No direct position feedback. Actual position value via the rotary encoder of the servo motor.	Direct analog setpoint coupling, high-precision feedback via absolute linear scale
Wear	Wear-prone components, risk of damage in the event of a collision with the roller	Wear free

Below you will find the step response of a linear motor:

After a specified step of 50 µm (set value), the change is measured using the absolute linear measuring system (actual value). As can be seen, the axis and thus the electrode ideally follows the target.

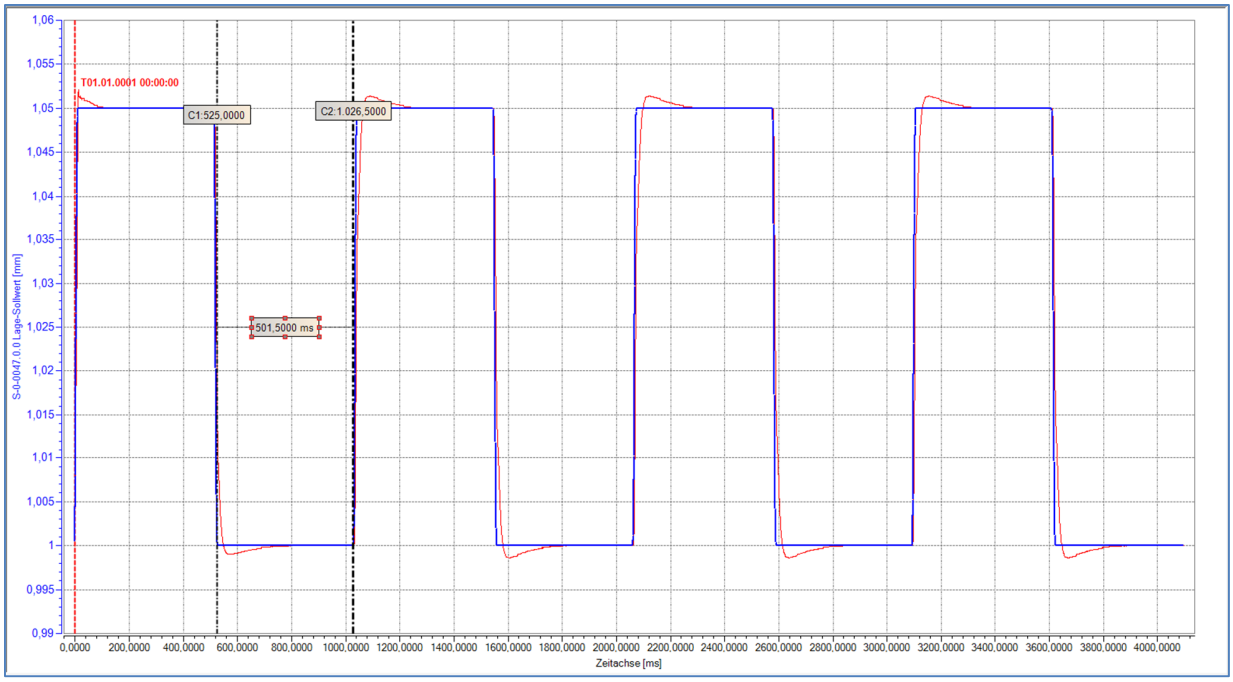

Illustration 4: Step response diagram of linear motor

4. CONTROL SYSTEM INNOVATIONS AND IMPROVEMENTS

The HMI system architecture is based on open system architectures to be installed according to customer request, e.g. Wonderware InTouch or Siemens WinCC. This standard component/license environment enables the end customer to modify or expand features according to his own standards. This open system approach fulfils both

- no black box scenario, but first-class high-end brands
- cheaper spares, as they are widely spread in the steel industry.
- easy maintenance, thanks to hardware and software products that are known and trusted in roll shops

The same applies to Host-connection and Level 2 interfaces.

5. FUTURE ASPECTS IN ROLL SURFACE TREATMENT

5.1 Is Laser Texturing an Alternative?

From time to time, laser texturing comes up as environmentally friendly alternative to EDT. At a glance, this seems to be right, however there are fundamental disadvantages:

Compared to stochastic (random) EDT finish, laser is a deterministic finish. Even if it is claimed that a stochastic roll surface can be “simulated” by laser, nature and especially the random distribution of an EDT spark cannot be simulated: It is a physical rule, that electrical current will follow the smallest resistance. This means the EDT spark will use the shortest distance, and therefore it is guaranteed that highest peaks of the roll surface will be removed firstly with EDT. This provides a very homogeneous surface with regularly distributed peak / valley ratio. With laser you will never know whether you will shoot the laser into a valley or on a peak. In addition to that, due to the very small laser size and the fact that the laser respectively the roll must be positioned (Z-axis infeed along the roll and roll rotation), a totally closed roll surface cannot be guaranteed. There is always a chance that some areas on the roll surface will remain “open” which means not textured.

To avoid these open spots, one approach is to increase the roll rotational speed. However, such high speeds (up to 250 rpm) are not possible to realize by supporting a roll in steady rests as it is standard for a CRM rollshop: The roll must be supported on centers. As the center holes are not being used after the roll manufacturing process, their geometrical condition is usually not suitable anymore due to rust, grease or color

markings. In some cases, the center hole is even not accessible anymore because the area is used for the roll identification and tracking sensor (RFID chip). Moreover, to support rolls on centers, roll attachments like pull-out hooks (or knobs resp. stars) need to be dismantled prior to laser machining. This is because the laser machine reacts sensitive to roll out-of-roundness due to very high roll speed. This manual dismantling is a “no-go” for an automatic roll loading process, as it is an auto cell (fenced area).

Finally, with laser texturing you have limitations in tuning your roll topography (e.g. low roughness with high number of peaks). Also, proven processes like Electrical Discharge Coating (EDC) or finishing of rolls after texturing are not possible. Moreover, a roll surface created by laser is not comparable to an EDT surface, because a laser creates waves instead of peaks: Most likely also postprocesses like deep drawing or painting must be adjusted because of different roll topography.

Above and the low production capacity (long machining times) makes a laser machine not suitable for a modern CRM rollshop.

5.1 Sustainability and Environmental Friendliness

Often, the EDT process is described as dirty and inefficient. However, the opposite is correct, please refer to below facts

- The used dielectric oils (universal spark erosion oils) are free of both, chlorine and heavy metals. The oil can be used permanently and there is no lifetime limitation resp. Besides that, there is no need for complete exchange, as the oil is continuously filtered.
- As filter media for the dielectric oil, standard EDM filter elements are used. The filter elements end caps, center tube and external housing are 100% made of environmentally friendly plastic (and completely free of metal). The loaded filter elements can be completely thermally disposed, e.g. are used in appropriate systems in the steel industry (furnace), in cement works or in waste incineration power stations as an additional source of energy and incinerated without leaving any deposits.
- An EDT machine is equipped with an air suction unit to exhaust fumes, vapors and odors generated by the texturing process. The used blowers consist of EC centrifugal fans, which are an energy-saving and long-lasting technology.
- In general, the EDT process is fast and efficient. The short machining times (e.g. 50% shorter compared to other texturing processes like laser) are based on the high efficiency of the generator (on a Kleinknecht EDT generator, an efficiency of 92.5% has been measured). This results in an overall low power consumption of EDT.

5.2 EDT Remains the "Working Horse" for Roll Surface Treatment

Over the past four decades electrical discharge texturing has become the standard surface treatment after grinding for cold mill work rolls. The automotive industry would not be able to produce vehicles with the same high level of gloss and shiny surface qualities that everyone is accustomed to. This applies in particular to the German automotive industry; however, the USA also produce wonderful car bodies. This industry will choose more and more aluminum for body parts. The future demand for the texturing of aluminum will increase as a result. Steel will certainly find more competition regarding the production of cars and white goods. Besides steel and aluminum plastic, and even carbon fiber, might require textured surface qualities one day.

More reasons to even further investigate and improve the long track record of generators (see figure 1). The next phase of EDT innovation will be the development of a new type of generator. This will be based on the operational modes of the current and well accepted type. On top of this the compact design and careful selection of the latest SMD components and powerful CPU types will boost the texturing quality and texturing time into a league of its own.

Bearing in mind the mechanical innovation just carried out followed by the new generator design, the EDT process supported by Kleinknecht will be ready to fully cover the market requirements for the next decade.

6. SUMMARY

The following table is a recap of all innovative ideas that were realized in the latest high-end EDT machine technology.

Area of Improvement	Customer Demand	Innovation
1. Mechanical Features	• no disturbance from gear box/clutch	⇒ torque motor
	• no guidance in the dielectric bath	⇒ outside guide rails
	• smart drive concept reduces no. of motors	⇒ central positioning + clamping
	• widest possible range of rolls	⇒ 1 electrode to 60 electrodes per roll possible
2. Texturing Performance	• reduction of cycle times	⇒ independent multi-functional cart (MFC) ⇒ independent machine

		cover
3. Texturing Environment	• most accurate and highly dynamic gap control	⇒ linear motors (not ball-screw system, no servo-hydraulics)
	• no magnetic/electric influence	⇒ linear motors (non-ferrous design)
	• constant electrode flushing pressure	⇒ closed loop pressure control
	• no bath contamination with hydraulic oil	⇒ smart tub design: no leakage into tub possible ⇒ analysis of dielectric oil: trend voltage strength
	• no bandings	⇒ mirror image grounding system ⇒ identical copper-busbar resistance
4. Generator	• Eight (8) modes of operation	⇒ (Pulse if/ie, CAP pc/cc, +/- polarity)
	• roll edge preparation	⇒ individual firing unit parameter selection
	• ignition/spark verification	⇒ selection of good/bad spark ⇒ less short-circuits, less misfire

Illustration 5: EDT Innovations overview

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