Modern Production Concepts in Plasma Nitriding

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Introduction

In the late 70th *ELTRO* developed the pulse plasma technology with variable duty cycle pulses and hot wall reactor, opening a complete new world of possibilities in plasma nitriding. This system is now state of the art and allows the easy treatment of more parts with better quality at lower price per part. Modern concepts which use the full advantage of this technology push it to the leading edge of modern high volume thermochemical treatment.

Nitriding

Most of manufactured parts have significant performance requirements at or near to their surface. An optimal selection of the surface treatment is crucial for the performance. Nitriding and nitrocarburizing can economically protect parts against wear and corrosion with the formed compound zones in the outmost layer of up to appr. 20 µm and in addition form an underlying diffusion zone which is much thicker up to 0.6 to 0.8 mm which support the compound zone and strongly improve fatigue behaviour. Modern pulse plasma treatment capabilities allow the optimisation of both layers to take full advantage of the different behaviour of the layers summarized in table 1.

Layer	Properties	Behaviour
Compound -	High hardness Low adhesion	Good resistance against wear and deformation
	Passivation capability	Increased corrosion resistance
Diffusion -	High strength	Resistance to contact fatigue
	Compressive stress	Increased fatigue strength
	Hot strength	Improved shape stability, reduced hot wear, increased thermal fatigue resistance

Table 1: Properties and working behaviour of nitrided layers. /1/

With the advantage of low energy and gas consumption parts machined to their final dimensions can - without distortion - be treated economically in a pulse plasma system to their optimal behaviour.

The distinct advantages are:

- Economically low demand on resources like electricity and gas
- Good reproducibility
- Good uniformity

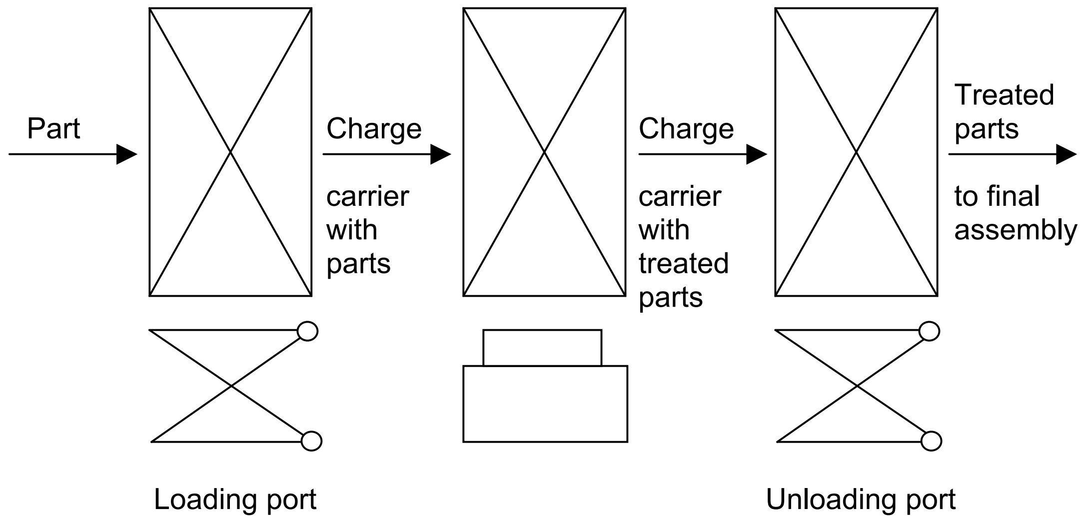
- High process flexibility. Overall performance in between wear, fatigue and corrosion can be optimized
- Environmentally friendly
- Safe process, can be integrated directly behind the last machining operation
- Treatment only where necessary, compound designs are easy to make

Basket ware cannot be treated. Plasma needs a gap between parts of more than 0.6 - 0.8 mm. This is not a real disadvantage, because it allows easy covering of areas not to be nitrided and is in automated systems always the case, because robots need space around the parts to grip them.
Optimal use of the possible operating time and the reduction of man power is crucial for the economic success. Modern systems achieve both.

Modern pulse plasma devices

Because of the necessity not only to transfer heat from the wall to the load like in a furnace but to transfer heat from the load to the wall like in a chemical reactor concentrical designs are mostly used. Depending on the adaptation of the load, hanging or staying pit or bell designs are used. Both types can be loaded manually or automatically. Most important for manually loaded devices are the decoupling of furnace running to load / unload times. This can be done externally by charging the parts in charge carriers manually and exchange the carriers with the parts in several minutes or internally by adapting a second base to the device and load / unload the second base while the first one is running. (Fig. 1)

1.) Part handling with moved charge carriers



2.) Part handling with moving bell (Double bottom system)

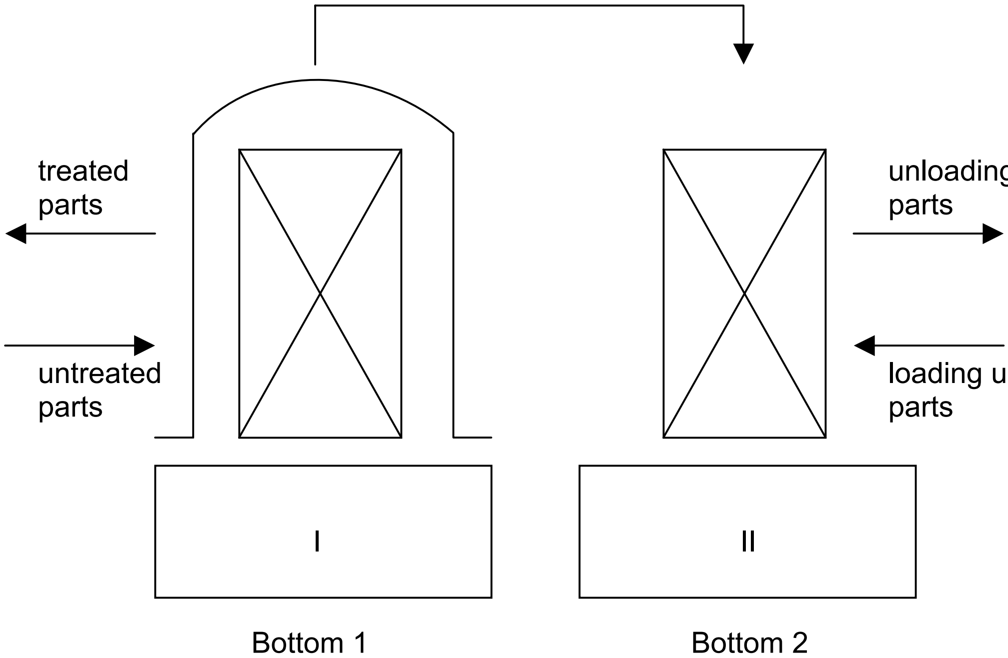


Fig. 1 Furnace Concepts

The latter system has the advantage of changing the load and starting a following process even when no labor is available for instance in the night. Customers like die shops like this system very much.
This system makes optimal use of the capital costs which are typical in the range of 60% of the overall cost.
Another 35% are labor, which can be reduced by automatic loading. Depending on the parts two different loading philosophies can be realized. In case of the double bottom furnace a robot can load directly into the furnace which results finally in the patented *ELTROPULS* Plasma-Cell concept which is extremely economic because one robot can not only load two plasma units with heavy parts of for instance 20 kg but can do additional work like loading / unloading the parts into a washer carrier or measurement devices, markers etc. All this can be done at a very low price giving write-off times of less than one to two years.

Loading charge carriers outside and transfer them into the plasma unit demands two devices, a robot to load the charge carrier and a charge carrier transport system. The plasma cell system above is mainly economic for one to two plasma units with long treatment time. The charge carrier loading with the carrier transport system is favourably useful for more than 2 plasma units or high volume applications with short treatment times. Both systems are shown later.
Last but not least cost reductions can be achieved by the designer. Because of the excellent reproducibilities of the Puls Plasma System tolerances can be defined tighter. To get 12 ± 2 microns of pore free compound zone you don't have to create 25 µm and in worst case, as some people do, grind 10 µm away, you operate directly on the target of 12 µm. As long as the material is not varying too much you get it. Off course modern equipment helps to spare money. Heat up times are speeded up by special heat up cycles and rapid down cooling not only spares money but also improves your metallurgical results /2,3/.
As important as the above outlined points are the capability of the plasma unit to treat large square areas of surface in a furnace.
Confusing informations are circulating. So shows the definition of a temperature uniformity in a plasma unit without the definition of the load and the plasma parameter lack of knowledge as easily can be shown.

Power input is:

$$E\ input = Voltage \times Current\ density \times Duty\ cycle \times Part\ surface\ area$$

To get rid of the energy you need a temperature difference between the different parts in the load and the parts and the wall. Because the practically only heat transfer mechanism is radiation the power output is:

$$E\ output = Constant \times Envelope\ of\ the\ parts \times (T^4_{RAD} - T^4_{WAL})$$

As everyone knows the surface area can be very big compared to the surface envelope. Compare a gear to a cylinder same diameter, the gear has easily double the surface area compared to the radiating envelope.

So, important is to reduce the plasma current density to the minimum level necessary to achieve the thermochemical results on the surface to be treated.
The *ELTROPULS* System with the patented Ignition pulse (DP 3322 341 etc.) produces a stable plasma under all circumstances and allows more parts with better quality to be treated in the same volume.

So modern Pulse Plasma Units offer an economic trade off between use of the equipment, labor cost and processing.

Examples

Obeying the outlined facts above showing that an in line integrated automatic system with optimized process gives the best economy with highest quality.

Annexed are some examples of delivered lines producing pulse plasma nitrided parts 3 shifts seven days in the week with only a small amount of man power.

First an example of a system nitriding automotive valves. (Fig. 2)

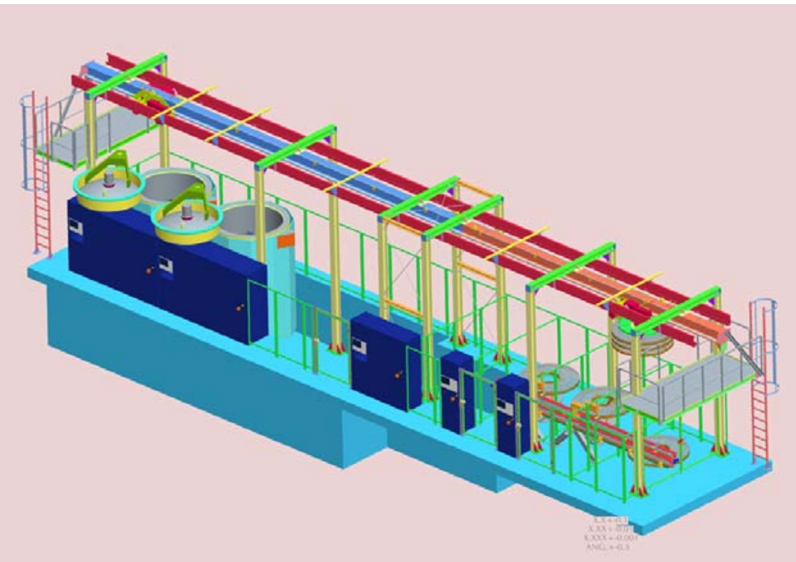


Fig. 2 System Nitriding Automotive Valves

This is a typical high volume production line with times per part of less than 0,6 s which means 120.000 valves / day giving a high burden on the automatisation system. Parts are fed through and away by a conveyer. Three parts handled per time by a SCARA Robot which unloads and loads in one cycle. The charging racks are transported to and from stacks and into and out of the two pit furnaces via a charge carrier transport system which, because of the dense timing, is available to transport up to three carriers in one cycle inbetween the system. The treatment quality of such a system is excellent. Even for the steel X50CrMnNiNbN21.9 the thickness of the diffusion zone reaches 13 ± 3 µm. For the ferritic steel X45CrSi9.3 the variation in the thickness of the diffusion zone is about 24 ± 3 µm. /4/

An example of a rather big installation (8 plasma units, 1,8 m ∅ x 2,25 m height) for medium size parts of up to 2 kg is realized for balance beams and axles made out of 42CrMoS4. (Fig. 3)

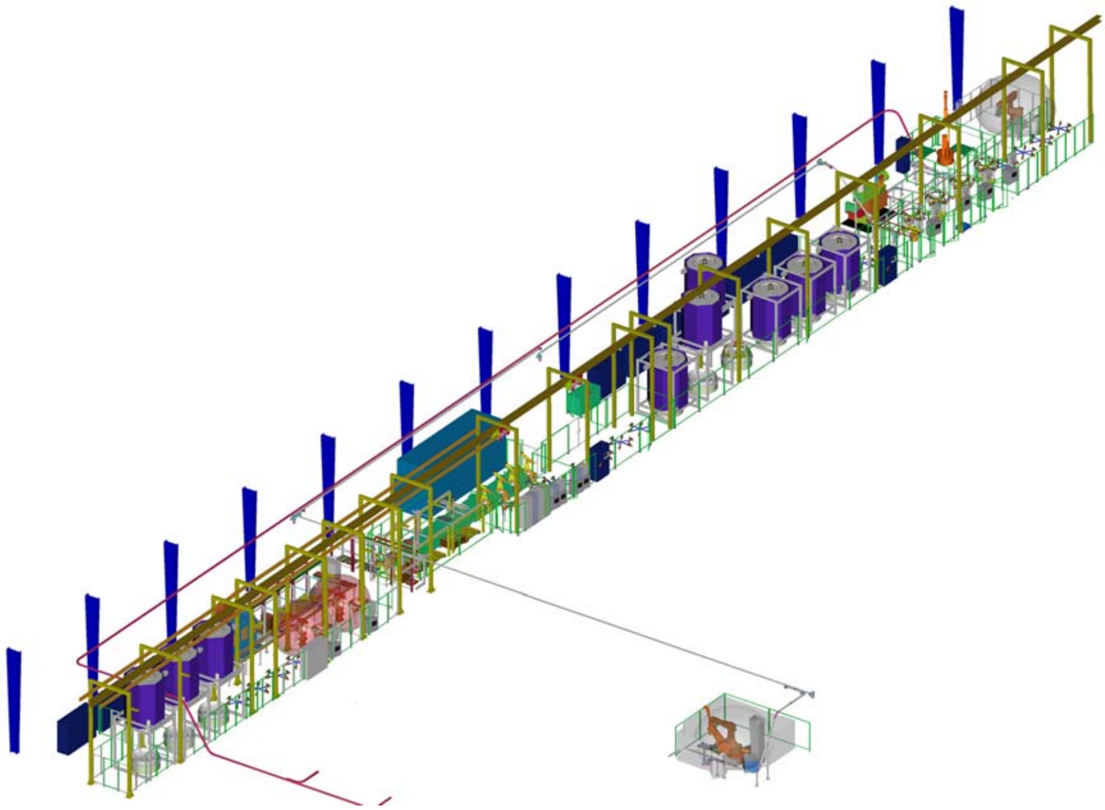


Fig. 3 System For Nitriding Balance Beams and Axles

The line is fully integrated directly in the production after machining and before assembling. The charge carriers for the different parts are coded and fit into every plasma unit making the system extremely flexible. Plasma units, several stacks and 8 loading stations are served by a charge carrier transport system, a fully automatic monorail crane with three runners because of the high traffic.
Loading and unloading and washing are specific for every type of part.

The leavers are transferred into the system via conveyer belt. They run through a spray cleaner to remove residual emulsion from machining. The conveyer are then split into four lines to serve four robot unloading / loading stations. There charge carriers are continuously unloaded into exit conveyer belts and loaded with the washed parts from the incoming conveyer. Typical time for an unloading / loading cycle is 3 to 5 s. So the theoretical capacity is in the range of 80.000 parts per day. The exit conveyer transfers the parts over about 100 m to the automatic assembly line. Alternatively parts can be stored with an additional robot in plastic container on EURO bases. The average compound layer thickness is 12 µm with a tolerance of ± 2 µm.
The axles are transferred from the last machining operation via dedicated plastic container stack into a 3 axis portal which is able to transfer untreated axles out of the container into an intermediate metal container and loads treated parts back into another plastic container stack. Empty containers are transferred from the input stack to the output stack by the portal too.

The metal containers with the parts are transferred via a conveyer chain into a 3 stage washing machine to remove residuals from the machining. The containers with clean parts are then transferred via the conveyer chain to two robot stations where treated parts are exchanged against untreated parts in one cycle. Cycle time is about 6 s which gives a theoretical daily number of handled parts up to 20.000.

Plasma Cell - A Flexible, Cost Effective System for Plasma Heat Treatment

A disadvantage of plasma processes has been the slightly higher manpower costs for loading and unloading. The plasma cell system developed by *ELTRO* GmbH overcomes this and increases cost effectiveness. (Fig. 4)

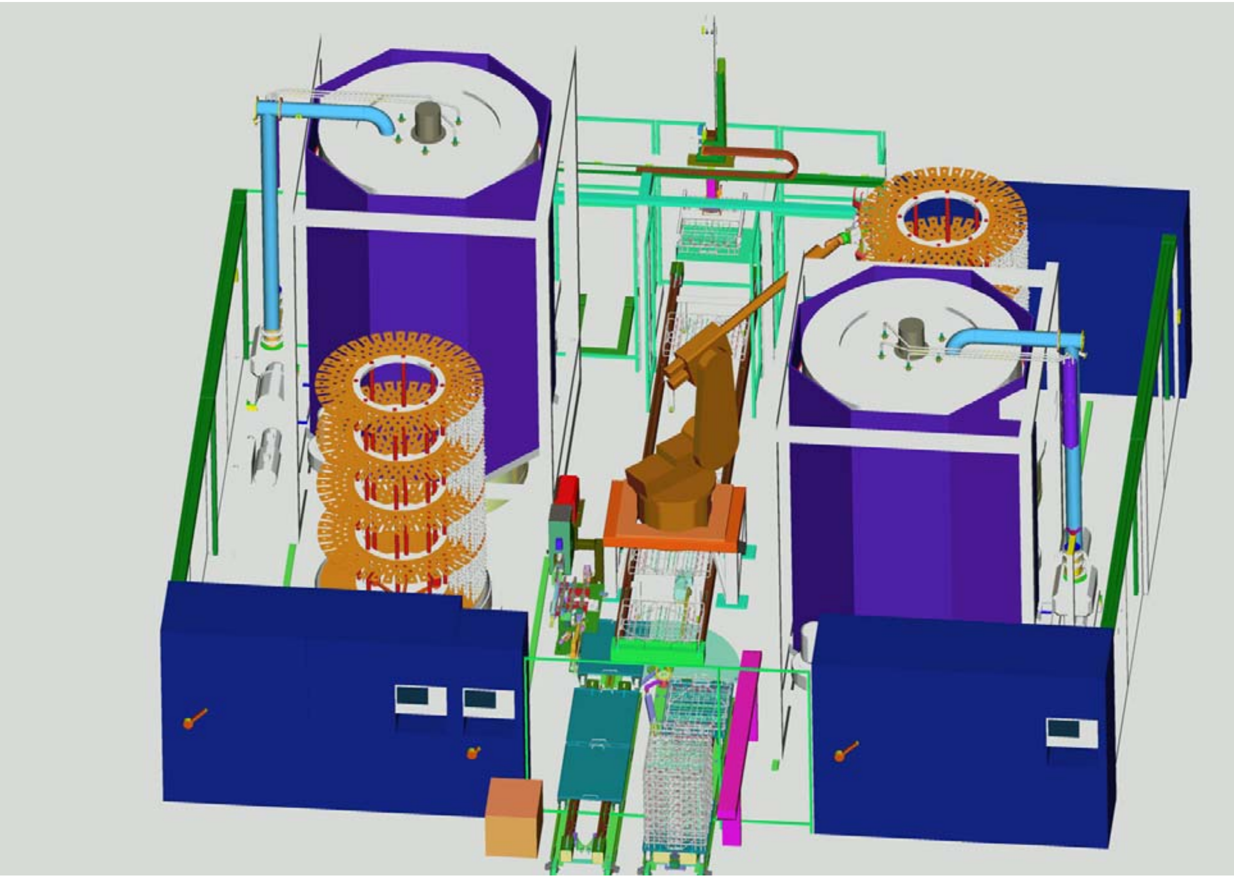


Fig.4 Plasma Cell

With little effort, a flexible automation is achieved so that personnel are no longer required to run the heat treatment unit. The return on investment for this automation is - in many cases - only one to two years. The plasma cell utilises *ELTROPULS* double bottom furnaces consisting of one bell and two furnace bases. A lifting device transports the bell to the bases. This type is used by many customers who wish to decouple the loading and unloading process from the nitriding process (e.g. tool makers).

The units can run continuously over three shifts - the loading and unloading is carried out on one base as the treatment is running in the other. The costs for a double base furnace are only slightly higher than for a single base furnace. A double bottom furnace can also be supplied with rotatable charging racks which can be numeric controlled and by then adding a robot a fully automated unit is created.

The cost of automatic loading can be halved by the installation of a second heat treatment unit within the working area of the robot. This is known as a plasma cell and allows a fully automated operation resulting in a reduction in cost and space requirements. For longer treatment times this automation has spare resources which can then be utilized for additional activities such as masking, jigging and labelling. Also, it is possible to incorporate packaging within the automated system. The automatic loading for the plasma heat treatment also provides the advantage that components can be sorted for further machining or assembly. Therefore the need for precise fixturing during plasma nitriding is no longer a disadvantage.

The illustration shows a system for plasma nitriding of eccentric shafts for an automated application. With the fully automated system for this application the cycle time is 20 - 30 seconds per part to carry out de-jigging, laser marking and packaging.

Summary

The use of plasma technologies offers important advantages to the user. With Pulsed Plasma Nitriding and the Pulsed Plasma Nitrocarburizing processes well defined layers for wear and corrosion resistance can be reproducibly produced. The operating lifetime and heat resistance of the part are improved. A plasma device can be integrated directly into the production line since no objectionable emissions come from the process. An important possibility for reducing costs consists of using high-speed cooling systems. The ignition pulse system guarantees highest loading density and lowest thermal differences. Processing costs can be significantly lowered by increasing furnace availability with fully automatic double bottom furnaces and by employing automatic loading and unloading systems that can handle substantial production quantities.

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