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A new industrial ion implanter for surface modification of metals

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Abstract

A new industrial ion implanter for surface modification of metals has been developed and built. Besides having all the features necessary for well controlled and efficient ion beam processing, such as high ion current capacity, ion mass analysis, large area beam scanning and sample manipulation, the new implanter is designed for industrial processing in production environment. With a new ion optics concept and layout the implanter is compact and only takes up 1/3 of the floor space required for traditional machines with similar performance. The implanter is fully computerised with automatic operation routines, data logging, remote operation and dial-up troubleshooting. The control software for the beam scanning and sample manipulation has been further improved in order to minimise setup time and to allow extensive use of the selected area implantation technique. This paper will describe the industrial implanter and the results of initial tests together with some industrial tribological and corrosion applications, which the implanter is aimed at.

1. Introduction

The early ion implanters for industrial service implantation were simple nitrogen implanters without beam position control, but it is well known that not only nitrogen ions but also metal ions are needed to optimize the effects of ion implantation on the tribological behaviours of materials [1]. Furthermore, experience gained at the DTI Tribology Centre over the last eight years with commercial service implantation has shown that specialized and efficient equipment is required to ensure the success of ion implantation into metals as an industrial process. With this in mind Danfysik and DTI Tribology Centre decided to develop an industrial ion implanter with the assistance of LEGO Engineering A/S in defining the requirements for application in a production environment. The aim has been to make a robust and efficient implanter which is simple to operate and which is capable of covering the majority of tribological and corrosion protection applications of ion implantation. Furthermore, the aim has been to keep the capital cost of the equipment down. The implanter should be optimised for nitrogen, carbon, oxygen and chromium beams since the majority of commercial applications for tribological and corrosion problems can be covered with these ions. It should make efficient use of the ion beam in order to make the implantations more cost effective. Beam currents higher than 10 mA is not needed and should be avoided because of the risk of overheating [2]. The implanter should be fully automated and have process control. The control system should incorporate data logging and remote trouble shooting.

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2. The implanter

2.1. Layout

The layout of the new implanter is shown in Fig. 1. The beam is extracted from the ion source at 50 keV and post accelerated to its final energy at maximum 175 keV before entering a 180° dipole magnet. Besides providing the mass analysis of the ion beam the magnet focuses the analysed beam on the target. The analysing slit is located in a low field region in the middle of the magnet. The beam position at the target chamber is controlled by two orthogonal scanning magnets. The "folded" beam path and the integration of the focusing lens with the analysing magnet results in a very compact layout with a footprint of only 15 m^2. This is approximately 1/3 of that of implanters with similar performance of traditional layout [3]. This is an important feature when fitting an ion implanter into an industrial environment.

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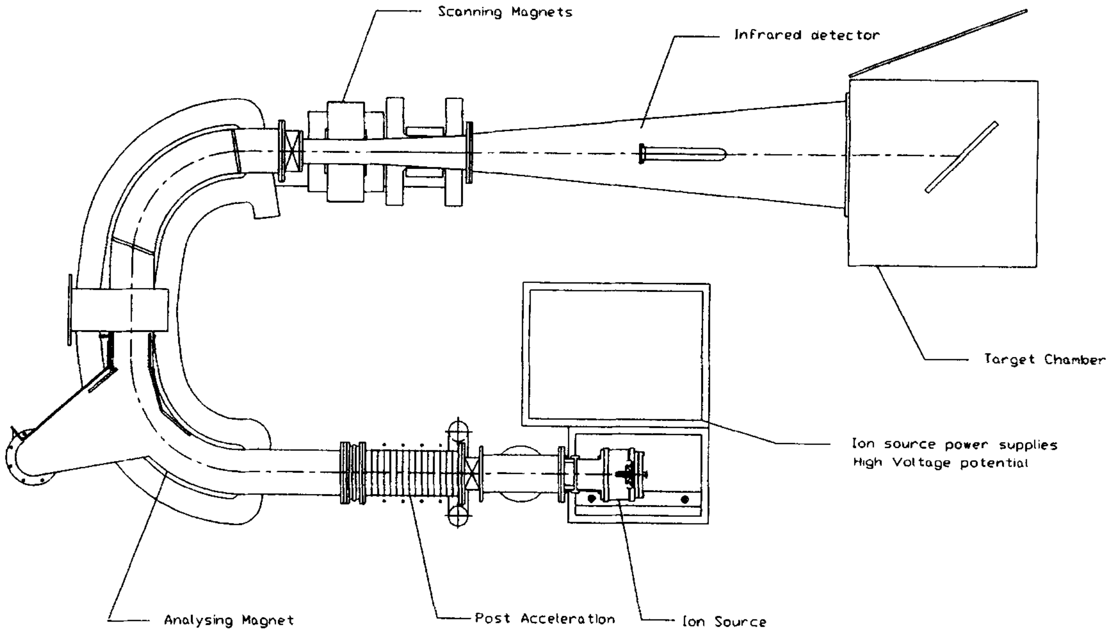

Fig. 1. The model 1100 ion implanter shown schematically.

The ion source and dipole magnet are pumped by two Ø160 mm diffusion pumps, the target chamber is pumped with a Ø200 mm cryo pump keeping the base pressure in the entire implanter in the 10^{-7} mbar region.

The implanter is enclosed in a housing which serves as protection against X-rays and high voltage. This is shown on the photo in Fig. 2. The door leads into a service area along the ion source section. Only the control computer

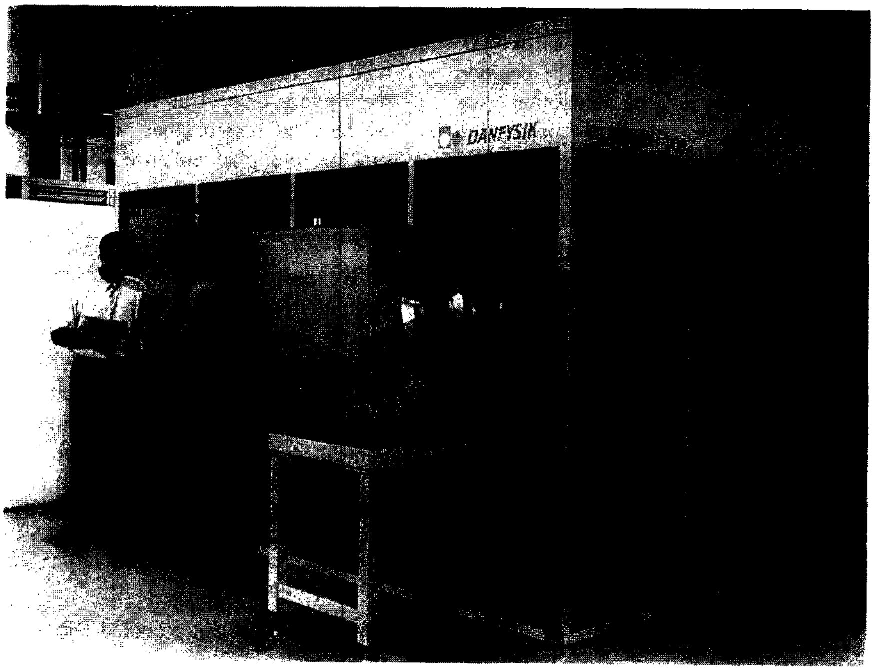

Fig. 2. The new industrial implanter.

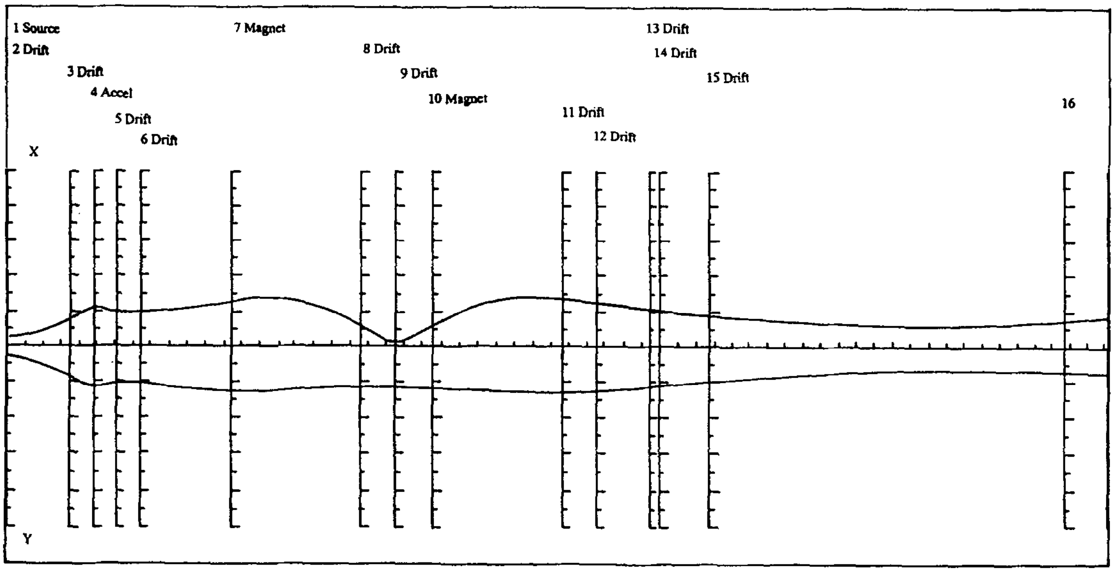

Fig. 3. The ion beam optics of the Model 1100 ion implanter. On the horizontal axis major ticks are 1 m and on the vertical axis major ticks are 10 mm. Position 16 is the target.

and the target chamber which needs regular operator intervention is accessible outside the housing.

2.2. Ion optics

The beam optics of the implanter is shown in Fig. 3. The figure shows the first order beam envelope from ion source to target position as calculated by the ion optics code OPTICS [4]. The upper part shows the horizontal (x) half width of the beam, the lower part the vertical (y) half width. In this view the 180° magnet is shown as two 90° magnets with a field free region in between. The position with a maximum mass dispersion is at the horizontal cross over point. A slit at this position selects the proper ion mass. The edge angles of the poles and the drift space are designed to provide a double focus of the beam at the target position. Furthermore, the dispersion at the target position is zero, which means that the beam spot position is very stable even in case of instability of the acceleration voltage.

The focusing effect of the acceleration tube has been calculated using AXCEL [5] and the effects of the dipole magnet by using TRANSPORT [6]. Since the acceleration tube has a weak focussing effect depending on beam current and the ratio between extraction and post acceleration voltages, some means of adjustment of the focusing is required. This is accomplished by remote adjustment of the pole edge angles of the magnet.

2.3. Ion source

The ion source is a modified version of the CHORDIS ion source [7]. The source has been redesigned and simplified to obtain easier maintenance and significant cost reduction. Extensive tests have shown that the new modified source give the same performance as the former version for nitrogen and chromium beams. The typical mass analysed beam current of these elements is 3–5 mA. The experience at DTI Tribology Centre has shown that such beam currents are adequate for cost effective service implantation work when using the selected area implantation technique [8]. Higher beam currents can give cooling problems. Alternatively, larger batches can be implanted, but this would require the large sample holders to be filled with the large batches of tools requiring the same treatment every time. This is not always possible. Therefore, we have addressed other more important elements in the process to further enhance commercialization of ion implantation into metals.

2.4. Beam position control and scanning

By means of the two scanning magnets and their computer controlled power supplies the beam position can follow any pattern on the target within a 40×40 cm^2 area, including a fast scan providing a 1600 cm^2 homogeneous implant area. The beam movement at target and the movement of the samples are synchronised and individually controlled by the same computer. The system allows localised treatment limited to the area that needs treatment [8]. This selected area implantation technique reduces processing costs dramatically.

2.5. Manipulator

The directly water cooled target manipulator has three movements, rotation, tilt and a linear movement. The maximum load is 50 kg. The manipulator has been de-

Table 1
Main specifications of the Danfysik Model 1100 High Current Implanter

Maximum ion energy	175 keV
Maximum ion current	10 mA
Maximum ion mass (@175 keV)	52 amu
Beam scanning area	1600 cm^2
Focused beam size	1–2 cmØ
Overall dimensions	4.5 m × 3.6 m × 2.6 m (h)

signed for quick and reliable mounting of the tools by using a quick-lock system. The target chamber can be pumped down ready for operation in 10 min.

2.6. Control system

The implanter is controlled from a PC which communicates with the hardware via fibre optics wired ControlNet interface modules from Group 3. This type of modules have special transient protection in order to operate in an environment with a potential risk of high voltage transients.

The control software is based on the windows programs InTouch and InSupport from Wonderware and the user interface is configured with all graphical displays and push button menus. It includes automatic routines for operation and process control, logging of all process parameters, on-line troubleshooting and guidance using the reported symptoms, dial-up troubleshooting, and the entire manual and documentation of the implanter which can be reached any time during operation. For example the electronic manual contains slide shows of all maintenance procedures for the implanter.

2.7. Diagnostics

The temperature of the samples is controlled and monitored by a dual wave length infrared camera working in the temperature range 175–300°C. Behind the infrared camera is mounted a video camera. A live picture of the sample being implanted can be seen on the monitor and the cameras can be tilted or panned for monitoring and measuring the temperature in any spot on the tools. The system is used for over-temperature control of the tools and parts and is a part of the interlock system.

2.8. Specifications

The main specifications of the implanter is shown in Table 1.

The initial tests at Danfysik during the summer of 1996 has shown that the implanter meets the specifications.

3. Applications

Many companies have obtained significant technical and economical improvements by using ion implantation made at DTI Tribology Centre, and today these companies are regular customers of the Tribology Centre. Ion implantation has been most successfully implemented where it is possible to utilize the specific advantages this technique offers, e.g. in the following areas:

- Tools tempered at low temperatures (e.g. below 200°C).
- Precision tools whose shape may be altered by heating.
- Highly polished tools.
- Tools where, in addition to the enhanced life, refurbishment should still be possible.
- Very expensive tools since the risk of negative effects is very small.
- Rather large tools on which the wear area is relatively small.

In these areas ion implantation has become a second-to-none commercial surface treatment at the DTI Tribology Centre which also performs commercial plasma-nitriding, plasma-CVD (Chemical Vapour Deposition) and PVD coatings.

Thus, today thousands of tools and tool parts are implanted at DTI Tribology Centre each year, and at several tool makers' ion implantation has become an integral part of their specifications just like steel type and thermal hardening procedures. Most of these tools are delicate and rather large punching/bending and drawing tools for thin metal sheets and plastic injection moulds. To some extent commercial ion implantation is also performed on cutting tools for paper, meat and rubber. However, the potential number of applications on such tools is considered to be much larger than the present use of the treatment.

In order to illustrate the typical applications a few examples of improved tool performance by ion implantation are shown below. The results shown have all been obtained in real-life production.

Fig. 4. A punching tool for tin can production from Danish Carbide Tools A/S.

3.1. Punching / forming metal sheets

Forming/cutting punches and dies working very thin sheets of tin can material (see Fig. 4). The tool material is mostly AISI D2, Vanadis 4 (Uddeholm) steel, AISI A2 and AISI M3 steel. Tool failure is caused by seizing and mild abrasive wear. The tools are delicate high tolerance tools, most of which are rather large. They are implanted locally on the critical areas with nitrogen ions. As a result of ion implantation the tools last 5 to 10 times longer or even more. Although extended tool life is obtained, resharpening is normally done from the top, and the implanted layer on the punch/die is left untouched. The companies have observed that extended tool life is still obtained after several resharpening operations.

Drawing dies made of Vanadis 4 or AISI D2 steel. These tools work without lubrication on lacquered thin sheets. They are subject to abrasive wear, and to some extent seizing occurs. On an average, the tools normally last around 3 weeks. After nitrogen implantation, tool life is increased to more than six months.

3.2. Plastic forming

In Fig. 5 are shown field test results from plastic moulds subjected to corrosive attack near the air outlets. During the moulding process the plastic emits corrosive gases which attack the hardened steel mould parts locally at the air outlets. The life of injection mould parts which are subjected to corrosive attack can be enhanced by chromium implantation at the air outlets, typically 3 to 4 times. However, in other cases even as much as 12–13 times.

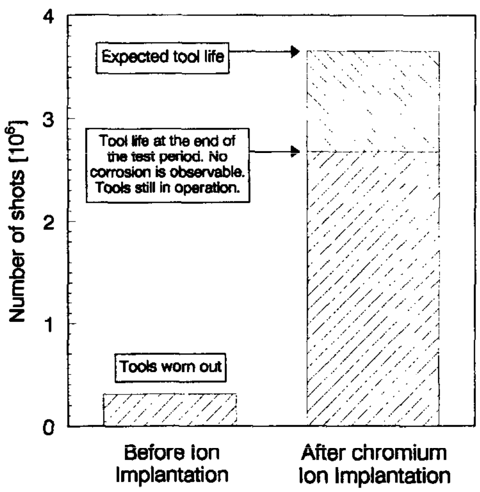

Fig. 5. Injection moulds subjected to corrosive wear at the air outlets.

Another example is improved performance of gates of injection plastic moulds subjected to abrasion. Nitrogen implantation of the gates resulted in reduced abrasive wear, and tool life was enhanced by 3.5 times.

3.3. Other work materials

Steel knives for cutting meat. Nitrogen implantation results in life improvement of 4–5.

Knives for cutting rubber. Nitrogen implantation results in 7 times life improvement.

4. Conclusions

We have designed and built a completely new ion implanter for industrial implantation work for applications on metals. The implanter will be performing service implantation work in the fall of 1996 for evaluation purposes. It will primarily be used on delicate and rather large punching/bending and drawing tools for thin metal sheets and plastic injection moulds.

Acknowledgements

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