Laser Assisted Forming Techniques

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ABSTRACT

During forming processes high deformations rates can lead to cracks and rupture very easily. Especially brittle materials like titanium or magnesium make difficulties in forming. Due to the dependence of the yield strength on temperature, forming at elevated temperatures eases processing of such materials. Since forming takes place only at localized areas of the work piece selective heating is sufficient and advantageous in most cases. Selective Laser heating offers a possibility to heat only the areas of the work piece where strongest deformations are required. For this purpose several laser sources have been tested like CO2, Diode and Nd:YAG Lasers and their advantages and disadvantages in localized heating of the work pieces will be discussed.

The work presented here summarizes research activities at the Institute for Forming and High Power Laser Technology, Vienna University of Technology, on laser assisted deep drawing, laser assisted bending, wire drawing and so on during the last decade. Recent developments like roll profiling, incremental forming processes and hydro forming are discussed briefly.

Keywords: Laser, Bending, Deep Drawing, Roll Profiling, Incremental Forming, Wire Drawing

1. INTRODUCTION

Recent industrial developments, especially in the automotive industry, aim on the reduction of work piece weight by using high strength steels or light weight materials like magnesium or titanium. Unfortunately, such high strength materials which allow a reduction of sheet thicknesses make forming operations like deep drawing, roll profiling or wire drawing difficult or even impossible

Several different possibilities of heat treatments will be discussed in the following sections as well as types of useful laser sources.

First of all, laser processing can be used to remove effects of work hardening from previous forming operations. For example the austenitic steel X15 CrNiSi 20 12 (1.4828) changes its structure to martensite during hydro forming. Martensite is very brittle and hinders the forming of the material. Usually a heat treatment process that increases work piece temperature to 1050 °C to 1150 °C with a following cooling in air or water is used to reverse the structural changes.

Hydro forming is a process in which a tube is placed in a forming die and is formed to the shape of the mold by internal water pressure in the range of several hundred MPa. Complex geometries have to be formed in several steps where each step requires a different die. Between each forming step heat treatment of the work piece is necessary due to work hardening. Since the martensite appears only locally at regions where the highest deformations took place heating up the whole work piece is not necessary. A selective heating by means of laser radiation can change the material properties to the initial values only at certain desired spots.

Another advantage is that the material flow can be influenced by the localized heat treatment. As a result the thickness of the work piece can be adjusted up to a certain degree.

Another type of heat treatment is to change the material properties during the forming process. As an example laser assisted roll forming will be discussed briefly. Roll forming is a continuous bending operation in which sheet or strip metal is gradually formed until the desired cross section is obtained. Typically, the forming action is restricted to a narrow region.

Usually the most important material properties for forming operations are summarized in flow curves. Such curves show the forces needed for plastic deformation. In most cases for a given material, elevated temperature

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causes a reduction of the forces and improvement of the deformation degree. Therefore a localized heat input shifts the material properties in such a way that the forming process is facilitated.

Experiments with the quenched and tempered steel CK75 (1.1248) show that with laser assistance it is even possible to deform that steel noticeably.

Finally a forming process will be discussed in that a laser beam is used as a substitution of the forming tool. Conventional wire drawing is a manufacturing process used to reduce the cross section of a wire by using a series of dies.

Per contra, laser assisted wire drawing uses different temperature levels within the wire together with well defined forces to replace the die. As an advantage the process avoids friction and there is no wearout.

Common to all laser assisted forming processes is that neither a small beam waist nor a long Rayleigh length is needed. As a consequence the diode laser is a preferential laser source.

Since high power diode lasers are assembled from many small laser emitters they can be easily arranged to suitable heat sources for the mentioned forming processes.

Additionally, diode lasers can be integrated into the forming tool.

Also Nd:Yag lasers are valuable tools for laser assisted forming since the radiation can be transported within fibers. Several thin fibers can be located at the spots where the energy is required. Only small changes of the tool are necessary since the diameters of the fibers are in the range of micrometers.

All the processes mentioned above have been examined successfully at the Institute for Forming and Laser Technology at the Vienna University of Technology.

2. REDUCTION OF THE WORK PIECE WEIGHT

In recent years the weight of vehicles, has been increasing as a result of the fact that more electronics (e.g.: electric motors for raising and lowering the windows or navigation systems), are being installed and the manufacturers focused more on passive vehicle safety (e.g.: side-collision protection,...). The heavier a car, the more fuel it consumes, meaning that car makers have to try to save the added weight somewhere else. This is why so-called lightweight manufacturing has established itself in automotive engineering.[1] Actually the car body accounts for only a quarter of the overall weight of an automobile.[2] It is well known that the fuel consumption can be reduced by a mass reduction of 100 kilogram by nearly half a litre.[3] The company Thyssen Krupp clearly demonstrated with the NewSteelBody concept that it is possible to reduce the weight of the reference model Opel Zafira by 24 percent or 75 kg. They used innovative processes like hydroforming or novel materials with higher strengths.

What is the task of a car body? On the one hand it should be able to absorb energy in the case of an accident, on the other hand ensure enough survival space for the passengers.[456]

Let us have a look onto materials for the building of a car body: The figure 1 clearly demonstrates that there are plenty novel materials with better properties than the typical steel FEP05 (DC05). On the horizontal axis the tensile stress is plotted: Tensile strength measures the force required to pull the sheet metal to the point where it breaks. The more tensile strength a material can withstand the less material is needed to build up a car body with the same stiffness. On the vertical axis you can see the elongation after fracture. We can take this value as a measure how ductile the material is. So there are materials with the desired properties for building a lightweight car body. But the established press lines are not able to form these high-strength materials. The use of self-hardening special steels like Transformed Induced Plasticity (TRIP) can be seen as a possible solution[13] .

Also the group of austenitic steels have quite good properties. In the Audi A6 already more than 20 kg of this material is used.[8]

Laser heat treatment can help to solve manufacturing problems which are caused by the introduction of the new materials.

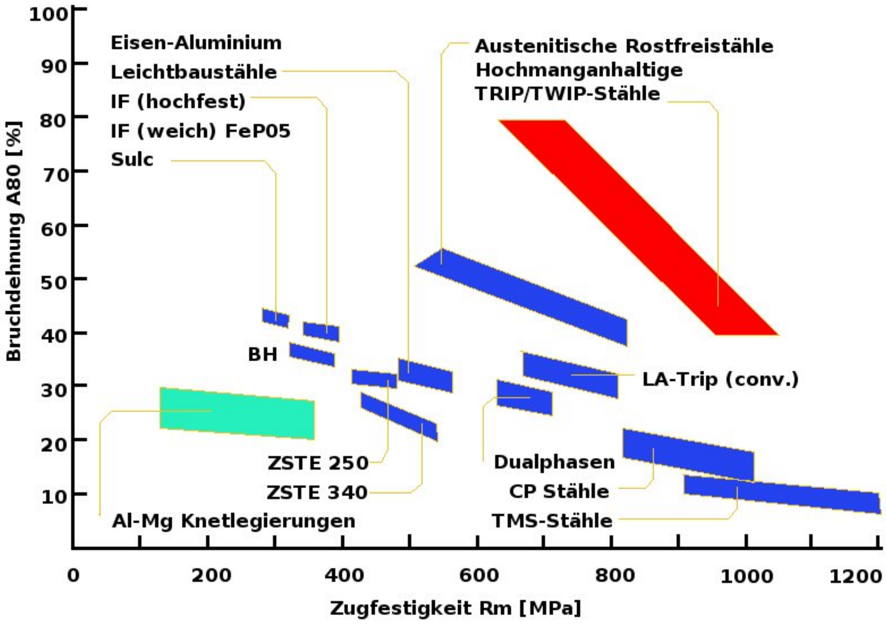

Abbildung 1. breaking elongation versus tensile strength[7]

3. FORMING OPERATIONS

The following enumeration shows a classification of laser assisted processes:

1. Localized changing of the material properties due to Laser treatment.
   - Hydroforming
   - Deep Drawing
2. The laser beam aids conventional forming processes.
   - Bending
   - Roll Profiling
   - Incremental Forming
   - Spinning
3. During a forming operation the laser beam influences the material flow
   - Deep Drawing
4. The Laser beam substitutes the conventional forming tool.
   - Wire Drawing

3.1. Localized changing of the material properties due to laser treatment.

In this case we are changing the material properties prior to a first or a subsequent of a forming operation.

Abbildung 2. Hydroformed Parts starting at the left hand side: After the first forming operation, after the second forming operation with in-between laser treatment, after the second forming operation without laser treatment.

Abbildung 3. Hydroformed Parts laser treated.

3.1.1. Laser assisted Hydro Forming[9]

In lightweight manufacturing, hydroforming has proven to be a suitable forming process.[10] The Austrian Company ELB Form is producing hydroformed parts out of X15CrNiSi 20 12 as you can see in figure 2. If the deformation degree is too high, it is not possible to make the final shape with the first forming operation. Due to the forming process the austenitic structure of the material is changing to a martinsite. This effect is called work hardening. By heat treatment it is possible to reverse this effect. Normally the hydroformed part is heated half an hour in an oven. On the basis of laser treatment it was possible to reverse the relevant areas within several minutes. It is not necessary to heat up the whole work piece. In figure 3 you can see the heating strategy as the colour of the work piece changed at the irradiated areas.

3.1.2. Laser assisted deep drawing[11]

In this paper there will be another section about deep drawing. The significant difference between this process and the one described subsequently is that in this case the sheet metal is already at room temperature when the forming operation takes place. The goal of the process is to enhance the formability of hardenable aluminium alloys due to a local laser induced heat treatment. Using of the correct laser parameter results in dissolution of precipitations and clusters.

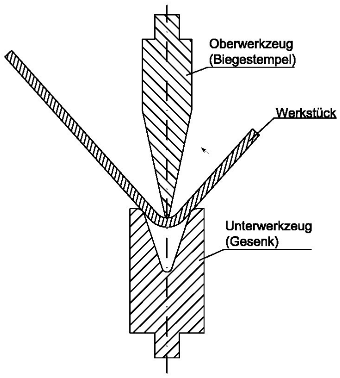

Abbildung 4. Laser assisted Bending: v-shaped die, punch[12]

Abbildung 5. Laser assisted Bending: Titan Grade 2, 2 mm, from the left hand side to the right: without Laser, test piece heated up to 250 °C, 450 °C, 500 °C, 550 °C[12]

3.2. The laser beam aids conventional forming processes.

It is well know that rising temperature helps metal forming operations. For centuries this feature has been used e.g. for forging. It is also possible to use this procedure in sheet metal forming.

3.2.1. Laser assisted bending

In figure 4 you can see the operation of air bending schematically. Having a closer look at the mechanical action you will realize, that the legs of the work piece are not influenced by the forming action. Considering that the sheet metal is extended perpendicular to the picture we need a heat treatment in a line to support the forming operation. Let us have a look on some test results with titanium regarding to the temperature using the same forming parameters. Figure 5 shows several samples of Titanium Grade 2 with a thickness of 2 mm bended at different temperatures. The aim was to bend an angle of 90°. At room temperature the specimen breaks, at about 250 °C there are some cracks, at 500 °C you get a good part and finally at 550 °C there is even no spring back effect anymore after bending.

3.2.2. Laser assisted roll forming

The first research work on this topic was done at 2000 in the framework of DFG Programm 1074.[13] Within the investigations it was clearly demonstrated, that laser treatment can improve the formability of CP-W 800 and MSW 1200. In the case of MSW 1200 the needed forces were reduced by up to 30%.

At the Vienna University of Technology we build up a small facility to make roll profiling with thin sheet metals. The sheet metal is fixed horizontally and two forming rolls are pulled along it by a servo motor. In front of

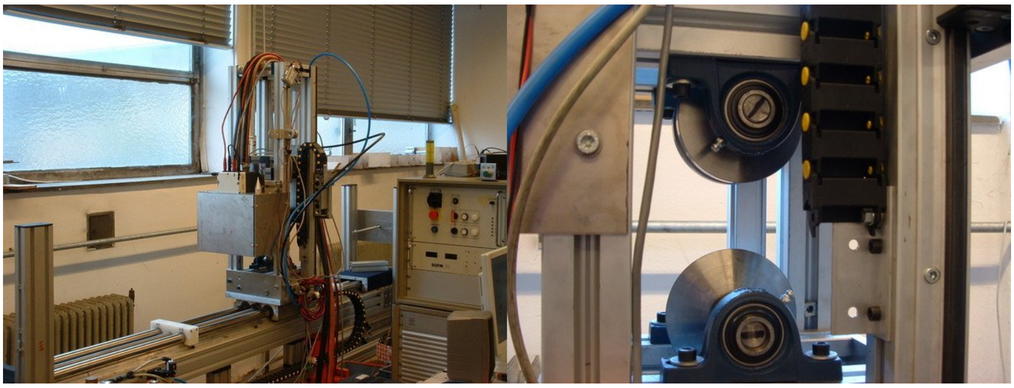

Abbildung 6. Device for laser assisted roll profiling of sheet metals.

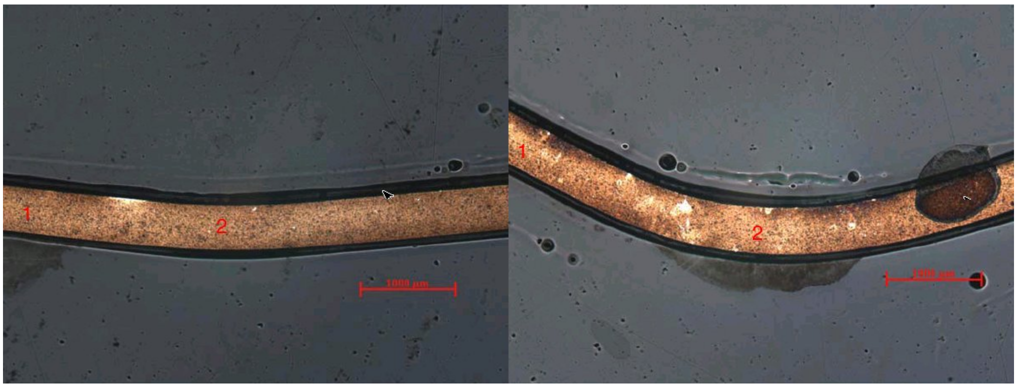

Abbildung 7. Cross section of roll profiled CK75: left side without laser heating, right side with laser heating (temperature 580 °C)

the rolls a diode laser with a beam output of 1kW is mounted behind an enclosure. You can see the experimental setup in figure 6. Investigations[14] on the heat treatable steel CK 75 with a thickness of 0.8 mm showed that roll profiling is even possible although the steel is hardened. The rolls seen in figure 6 were pressed together while the sheet metal was in between with a force of 1000 N. The bending angle in the case of room temperature is 170° at 580 °C it is 140°. The cross section is shown in figure 7. Increasing the force applied to the rolls leads to fracture. A polished micrograph section of two laser heated samples with the same beam power can be seen in figure 8. Both samples are located at the area where the laser beam heated the sheet metal. The picture on the left side shows the microstructure of the roll profiled sample. Due to the heating and forming process there is no change in the structure. The sample on the right side was just heated up without being in contact with the rolls for the reason of comparison. In this case the structure changed to a martensitic.

3.2.3. Laser assisted incremental forming

First trials[14] with the new process laser assisted incremental forming seems to be very promising. The process consists of several small plastic deformations with a spherical tool into a sheet metal leading to an overall deformation. Thus it is possible to build different desired hollow shapes, like one can do with deep drawing, with one single tool. The forming-force is applied to the sheet metal by a small ball as you can see in figure 9. The diameter is about 3 mm. The sheet metal is fixed in the same way like in stretch-forming and is manipulated by a Cartesian xyz-table. At opposite a kind of blank holder pushes the sheet metal back against the force of the forming ball. This blank holder is build up by a tube internally passed by a laser beam. This enables us to heat up the sheet metal opposite to the forming ball.

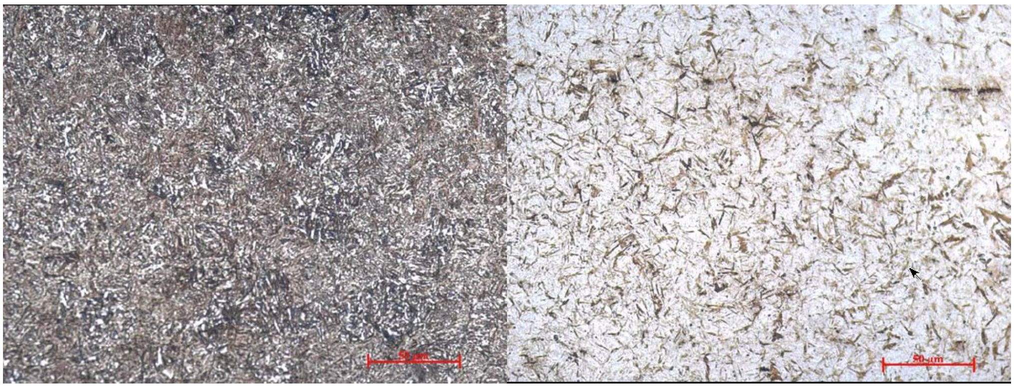

Abbildung 8. Polished micrograph section CK75: left side laser heated without roll profiling, right laser heated with roll profiling.

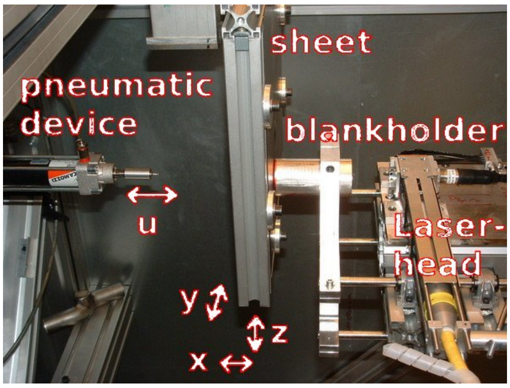

Abbildung 9. Device for laser assisted incremental forming.

3.2.4. Laser assisted spinning

This process was investigated by the Frauenhofer-Institut für Produktionstechnologie. The aim was to form materials like titanium or high strength steels with one clamping without making subsequent forming operations or doing heat treatments. Also in this case, due to the heat input, it was possible to reduce the needed forming forces.[15]

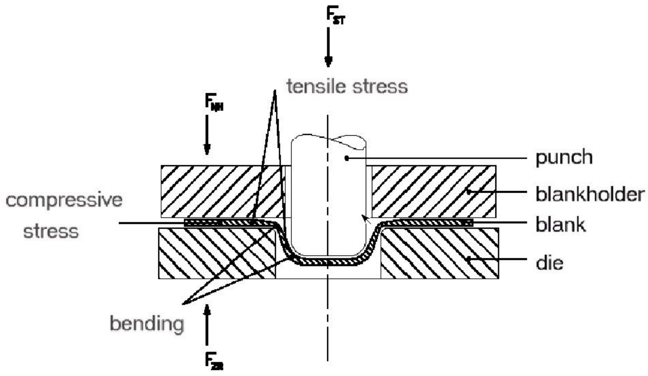

Abbildung 10. Laser assisted deep drawing: plan of cup drawing

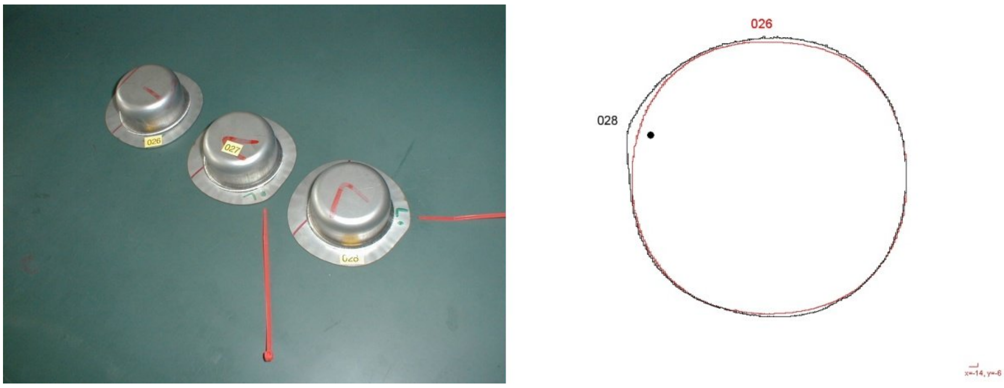

Abbildung 11. Laser assisted deep drawing: a point heat source changes the flange of deep drawing cups. The red marker is indicating the position of the laser beam.

3.3. During a forming operation the laser beam influences the material flow

3.3.1. Laser assisted deep drawing[16,17,18]

Deep drawing is a conversion of a flat sheet blank into a hollow shape by pressing it through a die, while the thickness remains essentially constant. In figure 10 you can see the simple process of drawing a cup. In the centre there is a circular drawing punch which moves the work piece into the die. The blank holder is holding down the sheet metal under a certain pressure onto the die. The force applied on the punch is induced into the blank via the bottom of the punch. In doing so it generates tensile stress in the sheet metal. But there is also an area where you have mainly compressive stress. The outer diameter of the circular blank has to be reduced to the diameter of the punch. It is only helpful to heat locally at the area of compressive stress. In this way it is possible to influence the material flow. The laser beam can be located at different spots on the work piece. Figure 11 clearly demonstrates the effect of a point heat source. Due to the tensile stress in the outer diameter a bulge is forming where the laser beam lowered the yield stress compared to the cold regions.

3.4. The Laser beam substitutes the conventional forming tool.

3.4.1. Wire drawing[19,20]

Thin wires are produced by drawing a thicker wire through a drawing die. Therefore we are confronted with the problems of work hardening, friction and wear. The solution is to make the forming operation without any forming tool. The wire is heated in a short zone and drawn. As the yield stress is falling with rising temperature and the drawing stress is above this value the wire will elongate in this heated small area. This process will stop

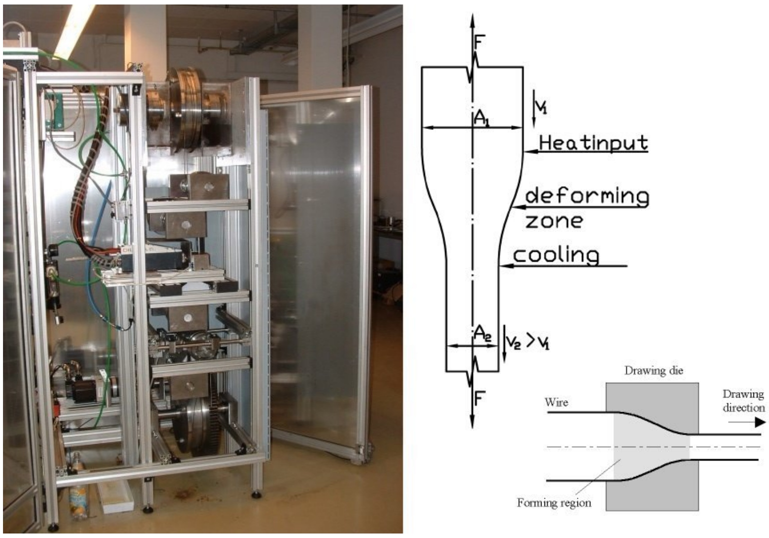

Abbildung 12. Laser assisted wire drawing: experimental setup

at the moment where another part of the wire is heated and the old one is cooled so that the drawing force is actually below the yield stress. As wire drawing is a continuous process, the wire is running down from a drum and collected by another drum. In-between the heat source has to be arranged. In figure 12 you can see an experimental setup at the Technical University of Vienna. The feeding coil is mounted at the top, the collecting at the bottom. In the middle there is a diode laser with a beam power of 1 kW located. Cooling is managed by a gas flow below the laser beam. As the wire is elongated the peripheral speed of the two coils has to be different. The coil at the bottom is connected to a servo motor, the top one to a break.

As a result it is possible to reduce the cross section of the wire in one single steep by about 20%. Investigations are going on to improve the stability of the system in order to reduce variances of the resulting diameter of the wire.

4. CONCLUSION

There are several lasers possible for the use as a heat source. Nevertheless in industrial use the processes will be managed by workers without any experience with lasers. The best solution would be to build up sealed off laser systems without the necessity for the worker to interact with the laser.

The warmed area has to be spacious compared to the possible beam radius of high power lasers. For prototyping the laser for sure is a very flexible tool. In mass production we also have to consider other heat sources. If it is advantageous to use a laser it seems preferable to use a diode laser. Due to its characteristic the beam quality is not first class but several laser diode modules can be mounted side by side and irradiate a larger surface.

Finally you can se in figure 13 an ideal combination of deep drawing with laser assistance. An 18 W laser bar is mounted below the blank holder. It is protected by an isolation layer and can be used as an add on tool in a conventional press line.

ACKNOWLEDGMENTS

The work on deep drawing and roll profiling was facilitated by the Federal Ministry of Transport, Innovation and Technology, wire drawing by FWF (Austrian Science Fund, P15175), hydroforming by FFG (Forschungsförderungsgesellschaft) and bending was supported by the company Trumpf Maschinen Austria together with FWF (P11821).

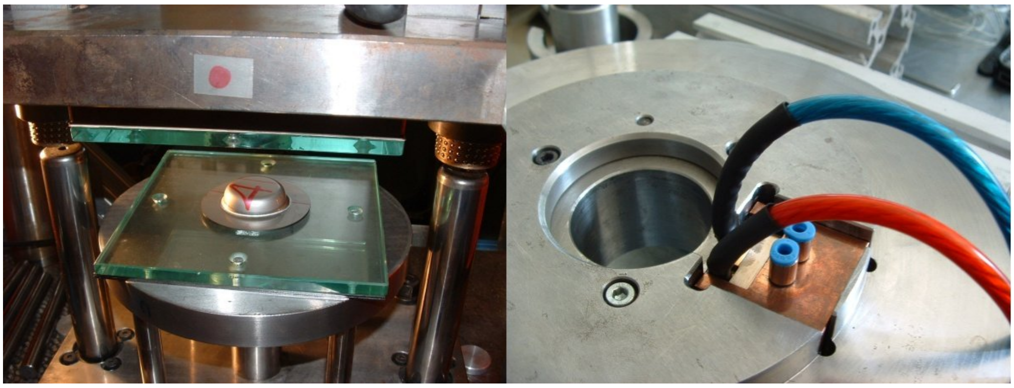

Abbildung 13. Diode Laser installed in a deep drawing tool

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