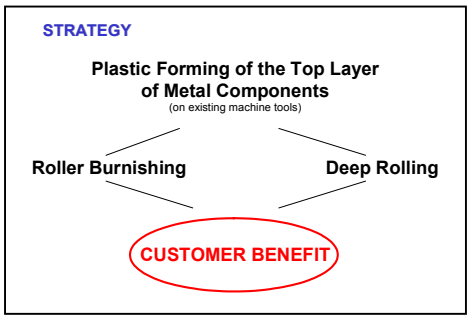
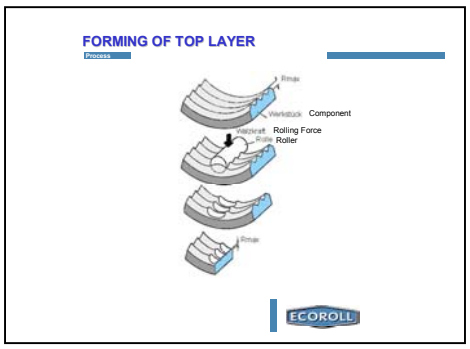
# Improvement of Fatigue Strength of Dynamically Loaded Components and Structures by Deep Rolling



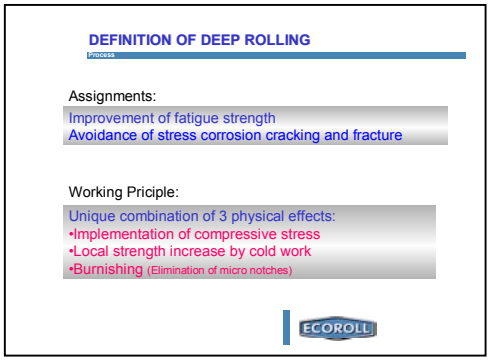

## Introduction

ECOROLL offers tools for plastic forming of the top layer of metal components. There are various customer benefits. **Roller Burnishing** provides very smooth surfaces at low costs. The process is very fast and can, in many cases, be completed right in one setting of the component after the cutting process. **Deep Rolling** improves the physical properties of components in the same very economical manner.



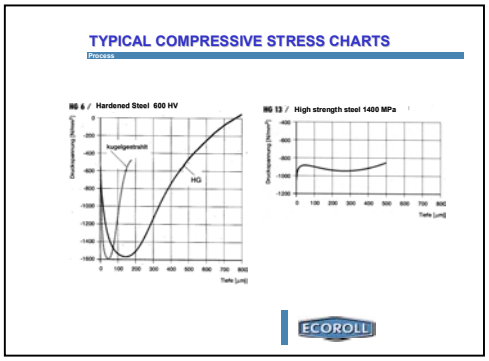

## Process

**Roller Burnishing** and **Deep Rolling** are based on the plastic forming of the material top layer. One or more rollers are pressed against the work surface with a rolling force, large enough to plastify the existing surface structure generating a smooth surface with only small remaining valleys. The sketch shows the effect only at one spot. Rotation of tool or work piece and according feed will stretch the effect over the whole surface.
Along with the change of the microstructure of the surface, the physical properties of the surface near material layer change as well. These changes, described later on improve the fatigue strength of the component significantly. If the process is applied to for this reason, it is called **Deep Rolling**. It is very important to distinguish both processes in spite of the similarity. Different working parameters have to be used and the measures of quality assurance are different.



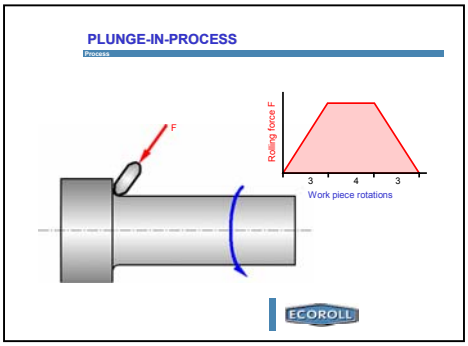

The **Deep Rolling** process is assigned for improving the fatigue strength, to avoid stress corrosion cracking or the critical results of Hydrogen embrittlement. An unique combination of three physical effects:

- implementation of compressive stress
- local strength increase by cold work
- burnishing (elimination of micro notches like machining marks)

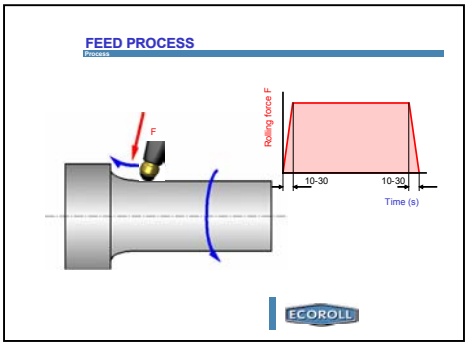



The residual compressive stresses after Deep Rolling show typically the following characteristics: compressive stress starts already at the surface, it reaches its maximum in some depth below the surface, becomes zero deeper down. Below the zero point, a small amount of tensional stress is implemented. Penetration depth to the maximum and to the zero point influence the efficiency of the treatment. In many cases, the largest possible figures lead to the best results. Larger roller diameters and higher rolling forces lead typically to deeper penetration. The left diagram shows the compressive stress characteristic generated by a hydrostatic tool with 6 mm ball. The right diagram shows the characteristic, achieved with the 13 mm ball

showing a substantial deeper penetration of the stress maximum. The maximal achieved compressive stress value depends only on the yield strength of the material. Deep Rolling tools can be made with a wide variety of roller diameters (typically from 1 to 250 mm). So the Deep Rolling process can be varied in a wide range to suit customer's requirements.




Small areas like fillet radii are typically treated in the plunge-in process with a few rotations and a straight infeed of the tool. The rolling force is gradually build up during the first rotations, is held at the maximum for a few rotations and gradually released over another few rotations




An dditional feed moves the tool along the rotating work piece. During the starting phase, the rolling force is gradually increased and it is also gradually released before the end of the treatment. This is very important to avoid any sudden changes of the surface near stress characteristic, thus to avoid a possible notch effect at the rims of the working zone.

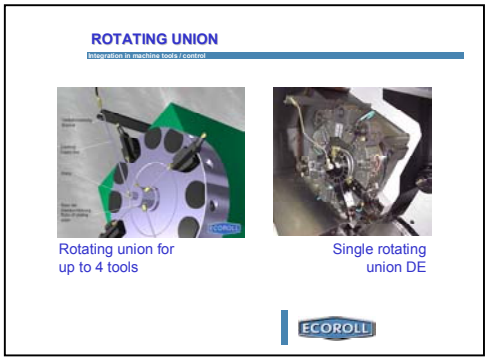

## Tools

A wide variety of mechanical tools is available, designed for specific jobs. They are spring-loaded. The rolling force is measured by monitoring the spring deflection.

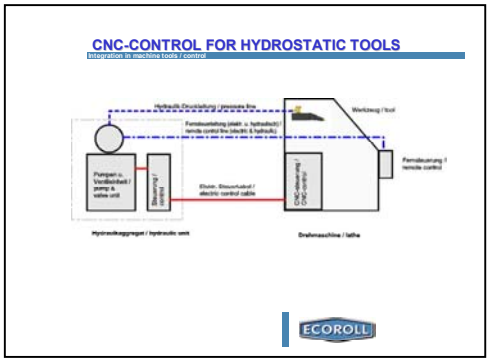

Hydrostatic tools are the preferred means for Deep Rolling. The rolling force is generated by fluid pressure behind the ball. In most cases, the coolant is used as pressure fluid to make the system compatible with the machine tool. The fluid pressure can be easily controlled and provides a reliable method of rolling force control. An automatic following system with several millimeters stroke ensures constant rolling force independent on form deviations, elastic deflections of the work piece or positioning errors of the tool. This system is available with square shank for conventional lathes, round shank for milling centers or with tool bodies with integrated high-pressure pump for CNC lathes with inbuilt tool drive.


Tools are available in with a range of ball sizes. The movie shows a hydrostatic tool Deep Rolling a ball section.

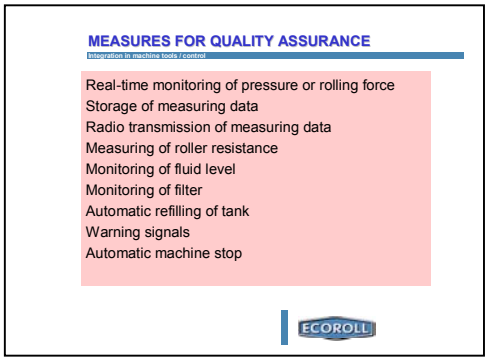
## Integration in the machine and process control



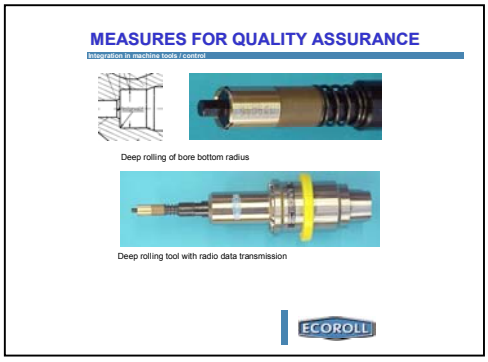

Square shank tools require an external pressure source (hydraulic pump unit). Rotating unions of different style are available to supply the pressure fluid to one or up to four tools mounted on lathe turrets.




The hydraulic unit is placed outside of the machine but connected with control lines to provide remote control of the pressure and CNC control of the whole process (start, pressure ramps and stop). The course of the tool is CNC controlled like with every cutting tool..

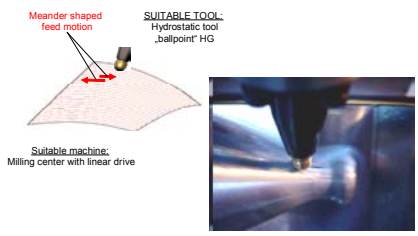



According to a risk assessment of an eventually failing component, the Deep Rolling process can be less or more tightly monitored and recorded as required




A mechanical Deep Rolling tool with integrated load cell and real-time radio transmission of the rolling force is shown for example.

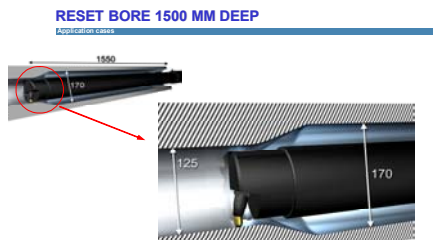
## Application Cases



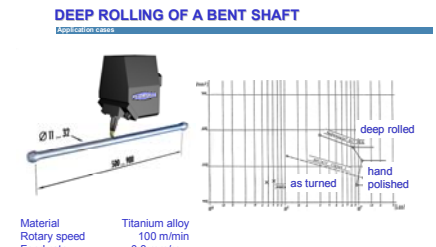

A hydrostatic tool is shown, Deep Rolling an irregular surface on a milling center. Due to the high velocity, the machine does not run the tool exactly parallel to work piece contour. This deviations are automatically compensated by the tool, keeping the rolling force nevertheless constant.


The outside diameter of a friction welded piston rod is deep rolled. This solution led to a complete elimination of the frequent fatigue fractures observed before.


Laser welds connecting different aluminum metal sheets are deep rolled on the milling center. The example shows only a linear straight welding seam. Curved welds can be treated as well.

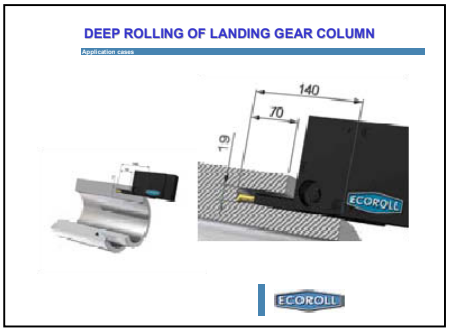



A complex internal contour of a1500 mm deep bore is deep rolled with a hydrostatic tool being attached to a boring bar. The elastic deflection of this long bar under the rolling force is compensated automatically by the tools following system.




Flexible bent shafts made of Titanium alloy and high strength spring steel alternatively are deep rolled with a hydrostatic tool. A fatigue life increase of about 50% against the hand polished version was achieved.


Aircraft wheels made of Aluminum alloy where formerly susceptible to fatigue cracks. They are deep rolled at various places and became fully reliable through this process. So they got permission to be back in the air. **Please note:** several hundred used wheels have been successfully treated. So the treatment of already used components is a serious method to eliminate fatigue problems on existing components.


Aircraft landing gear columns cracked at a very critical spot inside of a ring groove. Deep Rolling with a standard hydrostatic tool solves the problem. So, the airplanes are back on duty.


Through bores for bolts for instance in aircraft engine components can provide a substantial notch effect, leading to fatigue cracks. A hydrostatic two-point tool with a significant diameter compensation ensures constant rolling force in spite of diameter tolerances. This leads to very consistent compressive stress characteristic with the desired deep penetration.

## Summary

In process control of the working parameters
Optimal quality assurance
Hydrostatic or mechanical tools available
Integration in machine tools
Full CNC control of the process
Rotational and irregular surfaces
Deep Rolling is suitable for solid components and welds from small to large.