# Strain measurements for both formability testing and inspection of stamped parts

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**Abstract**

Strain analysis is used in sheet metal forming in two main fields of application:

- evaluation of formability testing like FLC-, tensile-, and bulge test, and
- strain analysis of stamped sheet metal parts.

This paper addresses both, the material testing and the stamped part verification, respectively. Exploiting the advantages of squared initial grids in either case the Nakazima test results can be directly compared with the strain state of a formed sheet metal component. High accuracy, reliability, and repeatability of measurements are achieved by the use of a pre-calibrated 4-camera *AutoGrid*® system.

## Introduction

Strain analysis is used in sheet metal forming in two main fields of application:

- evaluation of formability testing like FLC-, tensile-, and bulge test
  - to characterize the material behaviour,
  - to acquire input data for numerical simulation,
  - to provide formability limits for sheet metal parts
- strain analysis of stamped sheet metal parts
  - to assist the tool try-out process
  - to speed-up the launch of serial production
  - to assist in trouble shooting during production cycle,
  - to monitor process quality.

ViALUX engineers combined 20 years of experience in digital image processing with comprehensive knowledge in forming technology to build the powerful *AutoGrid*® tool for automatic strain measurement. An optimized 4-camera system has been designed based upon photogrammetry. The pre-calibrated setup offers two significant advantages:

- many measurements can be carried out with one calibration of proven accuracy

- dynamic strain development can be recorded as a time series (in-process mode).

The following two sections are to give a brief overview on *AutoGrid®* use for material testing and for the inspection of stamped sheet metal parts. The proof of *AutoGrid®* accuracy is given in the final section.

# 1. Formability Testing

## 1.1. Application in the FLC test

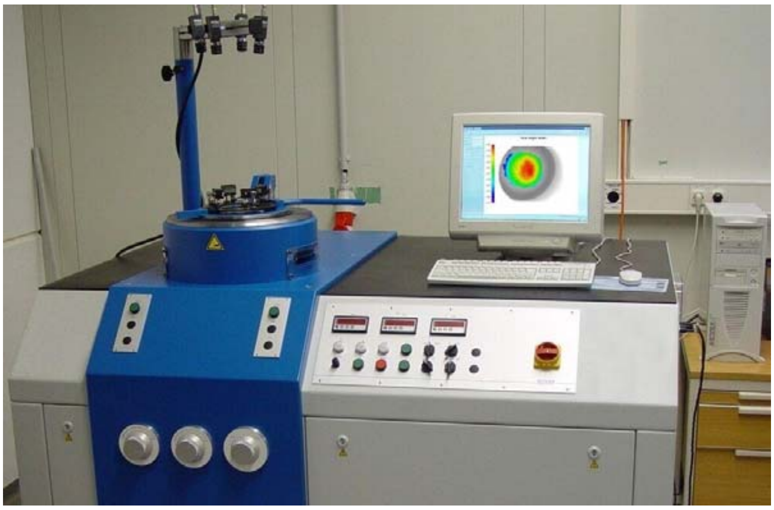

Figure 1. *AutoGrid® vario* system for FLC determination at BMW in Dingolfing

Figure 1 shows the *AutoGrid® vario* system mounted on a sheet metal testing machine. All four cameras observing the specimen from different perspective views are exactly synchronized to record image sequences with up to 15 x 4 frames per second.

There is the demand to determine the FLC values exactly in the moment before the material failure occurs. It is the point where instable local necking is followed by the crack. Of course, there is a need for a standardized procedure in sheet metal testing. One significant advantage of *AutoGrid®* is its ability to analyze and display the full forming history of the specimen, i.e. a 4D strain record is available. Automatic evaluation can be performed by detecting the local necking effects, see Fig. 2 and 3.

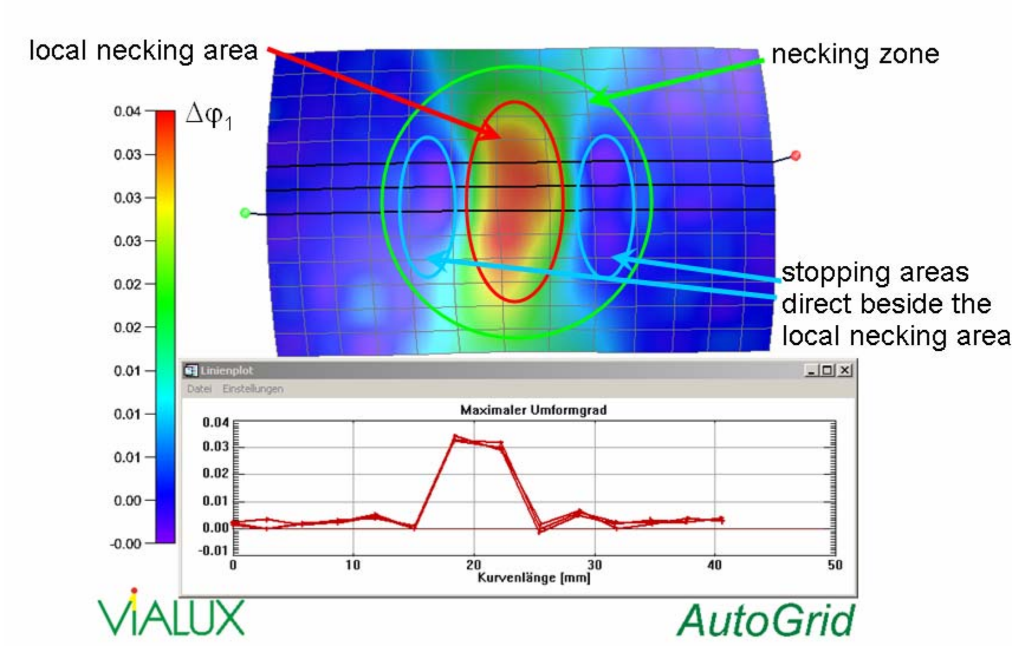


Figure 2. Incremental strain rate reveals local necking during an FLC test

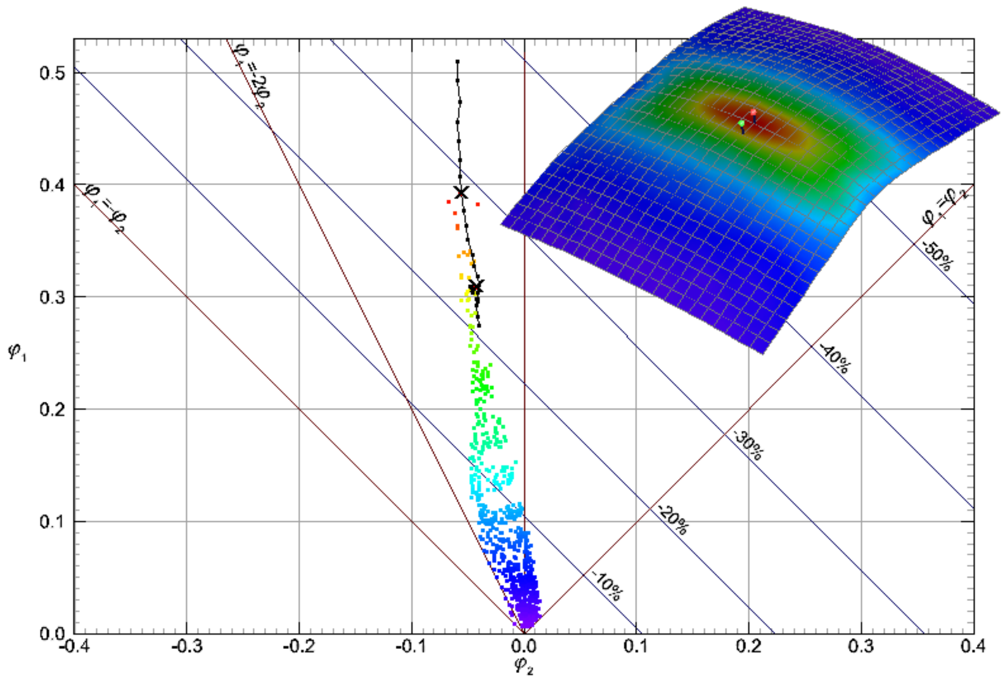


Figure 3. Strain paths of two selected points in the necking zone

## 1.2. Application in the tensile test

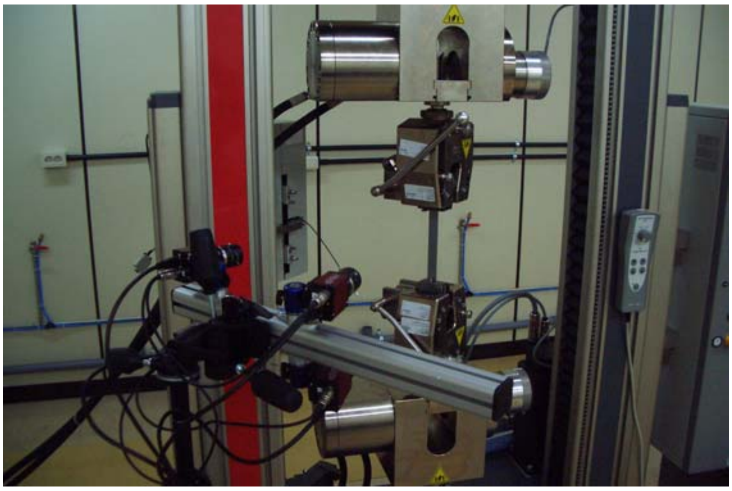

Figure 4. Setup of a tensile test using in-process recording techniques for strain analysis

The application of the *AutoGrid*® in-process mode is also very useful for the tensile test. Figure 4 shows the testing setup with a Zwick tensile testing machine and the *AutoGrid*® *vario* measuring device at our customer POSTECH in Korea.

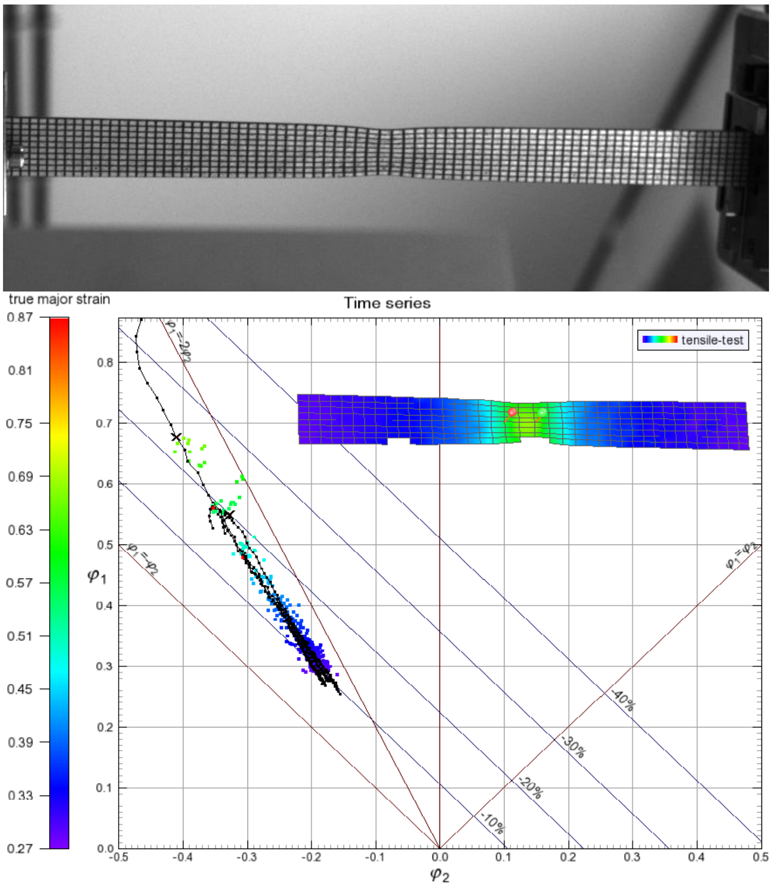


Figure 5. Results of a tensile test of DC04 before start of local necking with strain paths

The results make obvious that also in the tensile test of a ductile material (DC04) the stopping areas on both sides of the necking zone are detectable (see Figure 5). The green thumbnail marks a point in the local necking area. The strain path of this point reaches highest deformation values during the local necking before the crack. The red thumbnail marks a point in the stopping area. The two strains paths of points in the neighbourhood of the local necking area show the effect of the stopping area very clearly.

## 2. Strain Analysis on stamped Sheet Metal Parts

### 2.1. Design of the mobile strain analysis system *AutoGrid®* *compact*

The strain analysis system for measurements of deformed sheet metal parts should be usable not only in measuring laboratories but also in the press shop directly beside the press machines. So it has to be robust and mobile. But the use should also be very easy and convenient. Following these customer requirements the *AutoGrid®* *compact* device (see Figure 6) was designed.

Figure 6. The *AutoGrid®* *compact* system connected to a laptop and in action with operator

The *AutoGrid®* *compact* device designed for handheld use fulfils a lot of functions. At first there are the four fixed cameras for the photogrammetric measurement. Together with the high quality *Schneider-Kreuznach* optics the cameras are optimized to cover the grid markings also on complicated surfaces very easily in one shot (one picture of each of the four cameras). Because the cameras and the optics are safely fixed in the compact device housing measurements are possible without any setup and calibration stages.
The *AutoGrid®* *compact* sensor is calibrated ones and serves for many measurements with a well-known and proven accuracy afterwards.The 5.6 million pixel of the four cameras are

optimized in the *AutoGrid®* *compact* for typical applications in sheet metal forming. Additionally, the compact device includes LED illumination and the cameras can be adapted to all the different lighting conditions which can occur. For ease of the handheld use, the *compact* device includes a laser triangulation with two laser pointers. So it is possible to measure in one shot up to greater than 10.000 grid markings in a very short time (3-5 minutes) over a measuring volume of up to 480x360x150 mm³.
If desired, the *AutoGrid®* *vario* can be also adapted to any special customer needs.

## 2.2. Automatic stitching using additional coded markings

Often the strain analysis results should be presented not only over an area recorded by one picture set but over a larger area. Fully automated stitching is provided in the *AutoGrid®* system using additional coded markings. The magnetic targets are simply mounted on the part. In doing so, multiple measurements are stitched exactly giving one point cloud. Large objects can be analyzed easily.
Figure 7 shows an example of such a multiple measurement.

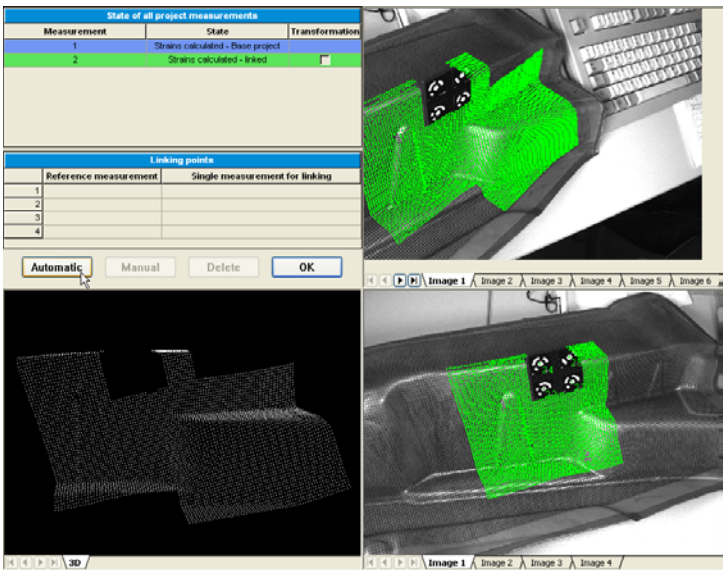


Figure 7. Example of automatic stitching

## 3. Verification of *AutoGrid*® measuring accuracy

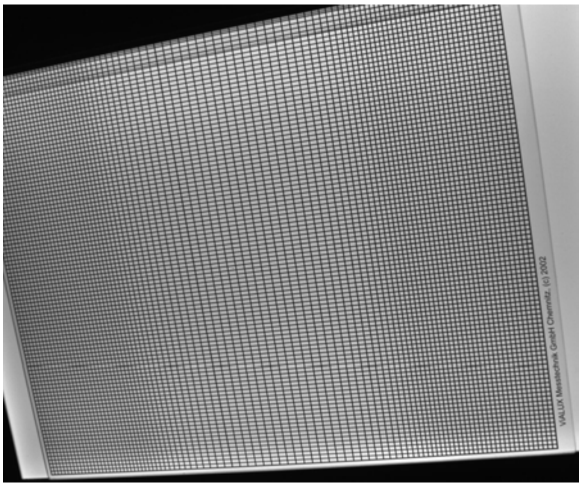

Figure 8. High precision master grid

The *AutoGrid*® accuracy is verified by means of a master grid made by high precision mask process as used in semiconductor manufacturing. The 2 mm grid spacing varies with 0.2 µm rms corresponding to a "strain" accuracy of 0.2µm/2mm = 0.01%. Therefore, the master grid is well-suited for the accuracy verification of the *AutoGrid*® sensor. The basic grid spacing of 2 mm is modulated in one direction to model major engineering strain values in the range of 0 -100%. The spacing in the other direction is fixed to model a minor engineering strain of 0% over the whole grid area (see Figure 8).

The following figures show typical *AutoGrid*® results of the verification measurement.

The measured strain values follow the master grid model perfectly. Starting at 0% on the boundary the major strain ramps up to 100% in the middle. The minor strain (green curve) is equal to 0% for the whole master grid according to the fixed 2 mm spacing in this direction.

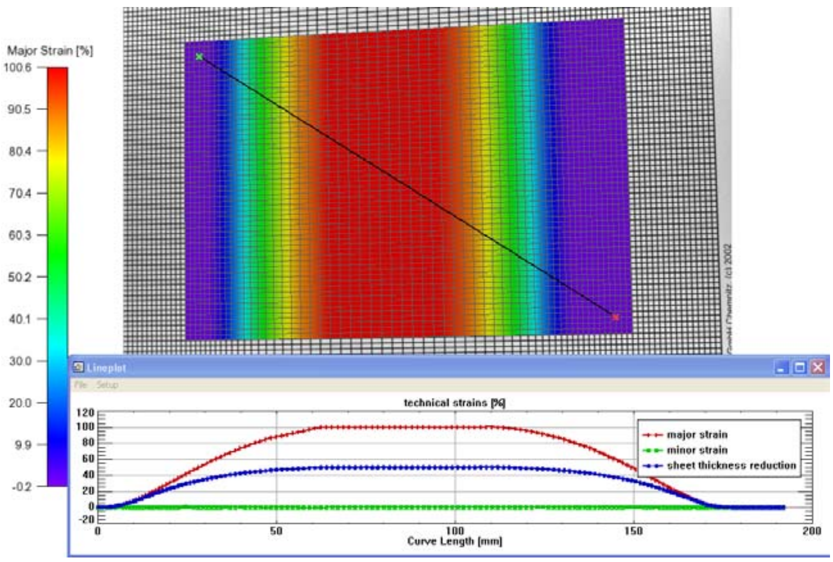


Figure 9. Measured strain distribution on the master grid

A vertical strain profile is given in Figure 10. The nominal strain value along this line is 100% and the graph shows

i) the precision of the absolute value measured by *AutoGrid*® and

ii) the low noise of the raw measured data.

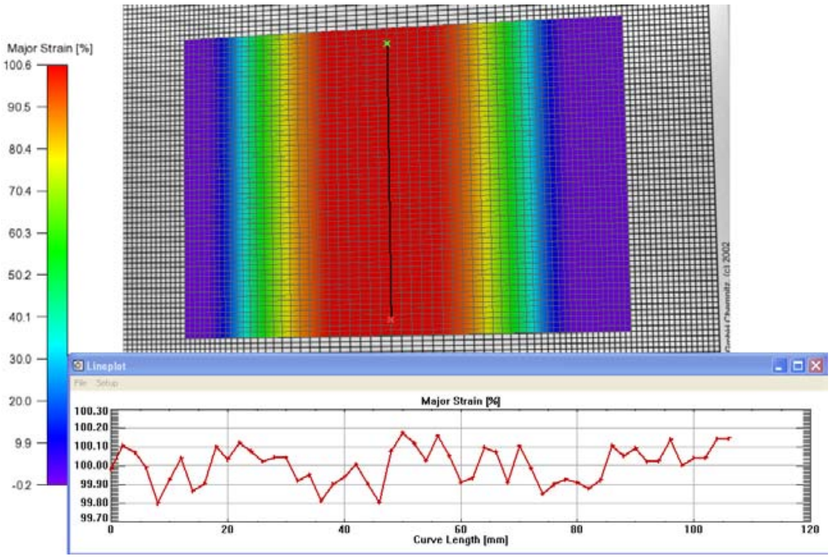


Figure 10. Measured major strain on the master grid

The *AutoGrid*® verification measurement proves the precision of the sensor; the standard deviation is ≤ 0.1% engineering strain. This value is found for both the undeformed and deformed area of the master grid.

## 4. Conclusions

The paper shows that the same measurement technology can be used for both formability testing and strain analysis on stamped parts. Material properties obtained from Nakazima test, Marciniak test, tensile testing or bulge tests can be unambiguously compared with the strain state found in the sheet metal parts in production. This consistency is an important benefit for quality assurance in sheet metal forming.

## 5. References

[1] P. Feldmann, M. Schatz: *Effective Evaluation of FLC-Tests with the optical in-process strain analysis system AutoGrid*®, Proceedings of the FLC Zurich 2006, 15th – 16th March 2006, IVP, ETH Zurich, Switzerland.

[2] W. Volk: *New numerical approach in the evaluation of the FLC*, Proceedings of the FLC Zurich 2006, 15th – 16th March 2006, IVP, ETH Zurich, Switzerland.