APPLICATION OF STRAIN ANALYSIS SYSTEM *AUTOGRID*®
FOR EVALUATION OF FORMABILITY TESTS
AND FOR STRAIN ANALYSIS ON DEFORMED PARTS

Peter Feldmann

AutoGrid® – strain analysis systems
ViALUX Messtechnik + Bildverarbeitung GmbH
D-09126 Chemnitz, Germany
e-mail: feldmann@vialux.de - web page: http://www.vialux.de

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Summary. *FLC and tensile test are presented as typical application examples of the strain analysis system AutoGrid® for evaluation of formability tests with in-process recording techniques. As in FLC tests in former presentations now also in a tensile test stopping deformation areas in the direct neighborhood of the local necking area are determined. Main specifications of the AutoGrid® compact system are presented to use it as a mobile system with easy handheld image recording in the press shop. A new automatic way to stitch single measurements together into one large linked measurement with use of coded markings is shown. Basics of an accuracy test for the optical strain measurement are described and results of such an accuracy test with an AutoGrid® system are reported.*

1. INTRODUCTION

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

1. **evaluation of formability tests** like e.g. FLC, tensile and bulge test
   to determine and characterize the forming behaviour,
   to get needed incoming data for numerical simulation,
   to have comparison data for evaluation of measured strains in deformed parts
   or as an incoming material test
2. **strain analysis of real deformed sheet metal parts**
   to improve the quality and production safety (mainly during die try-out),
   to solve problems during the beginning of series production or later during production,
   to use it for quality control management
   or to verify numerical simulation results (benchmarking)

The development of image recording and processing techniques in the last 15 years opens a lot of new possibilities in optical strain analysis compared to the old way: manual measurement of deformed circle grids. One of these new possibilities is the photogrammetrical 3d-measurement with a precalibrated camera setup after deformation or during the forming process, if the deformed surface with its markings is visible for the cameras. Normally in material formability tests like the tensile, the bulge or the FLC test this condition is fulfilled. The in-process capability offers completely new possibilities for material testing including forming history information. Such FLC testing equipment is shown in figure 1.

Figure 1. *In-process AutoGrid® system for FLC determination at BMW in Dingolfing*

The strain analysis system *AutoGrid®* is used since 2001 in material laboratories of several sheet metal suppliers, automotive OEMs and research institutes working on sheet metal forming. It improves basically the reliability and effectiveness of evaluation of FLC tests. A lot of other forming effects (e.g. considering also the forming history) in the up to date sheet metal development can be investigated directly in this way.

The use of strain analysis on deformed sheet metal parts indicates typical demands for strain analysis equipment for this issue. To fit all the typical demands the “compact” modification of the *AutoGrid®* system was developed.

To complete the presentation some information about testing of strain measurement accuracy will be given and typical results for the *AutoGrid®* system will be shown.

2. CAPTURING FORMING HISTORY IN FORMABILITY TESTS

2.1. Application in the FLC test

In a presentation on the FLC Zurich 2006 conference [1] the possibilities and advantages of using in-process recording techniques in FLC determination were shown. The main advantage is the possibility to determine the real FLC values directly in the moment before the material failure – instable local necking followed by the crack – starts.

Of course there is a big need to have a stable way independent of the operator to identify this moment. Two different possible ways for automatic detection of the beginning of local necking in the FLC test using a time sequence of strain analyzed picture sets recorded during the FLC test were also presented on this FLC conference [1, 2]. In both ways analysis of the forming history is necessary before the material fails by the crack. In the way of Feldmann and Schatz [1] the beginning of the local necking followed by the crack is identified by using 2 effects connected with local necking: the increasing deformation step width in the center of the local necking area and the stop of the deformation on both sides of this area (see figure 2).

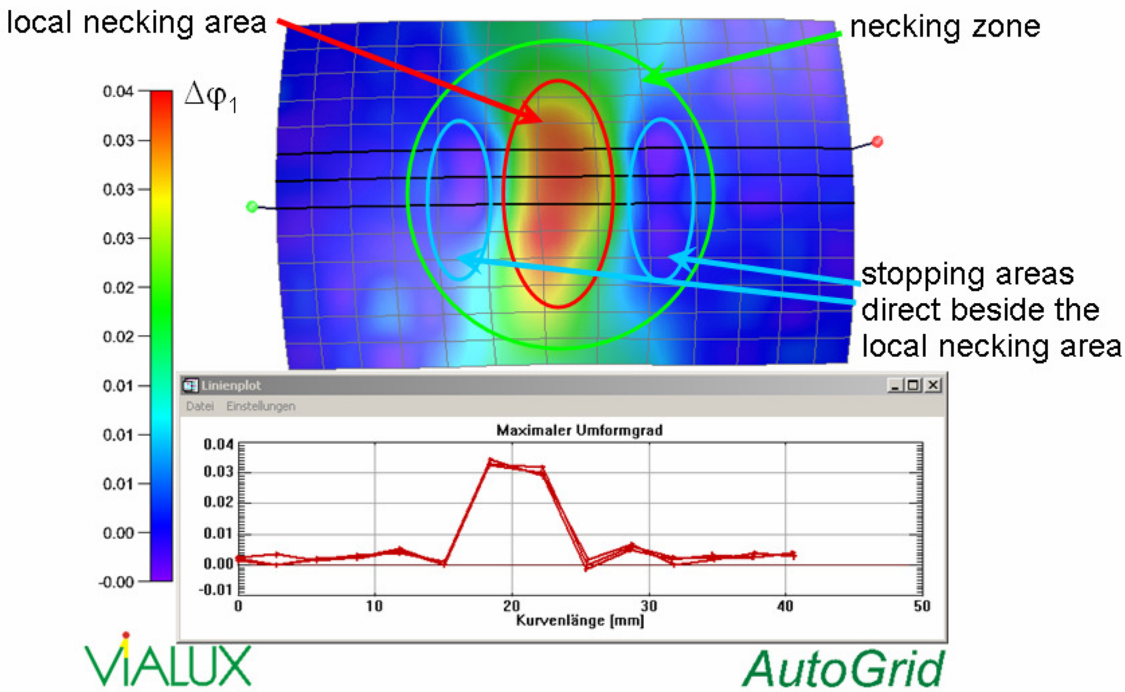

Figure 2. *Incremental strains during the local necking analyzed with an in-process recorded image sequence during local necking at the end of an FLC test*

The same effects are also visible in the strain paths shown in the FLD (see figure 3). On one side the step width in the strain path of the point marked with the red thumbnail increases during local necking and on the other side the deformation stops at the point in the direct neighborhood marked by the green thumbnail.

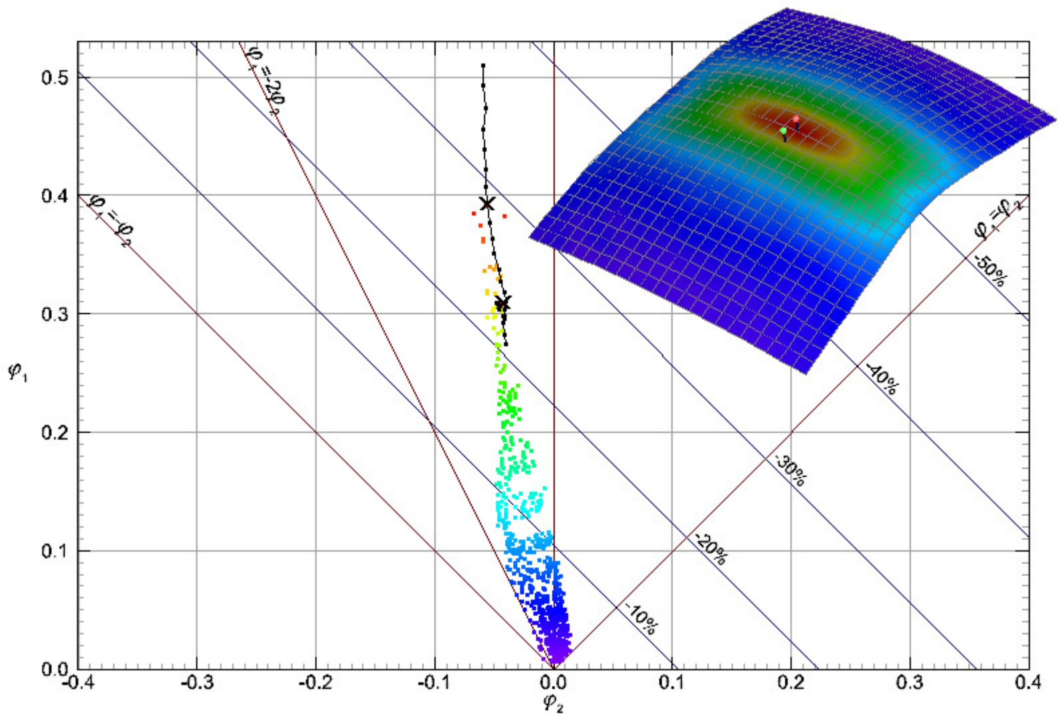

Figure 3. *Results of the moment before the start of local necking in an FLC test and strain paths of two selected points in the necking zone*

2.2. Application in the tensile test

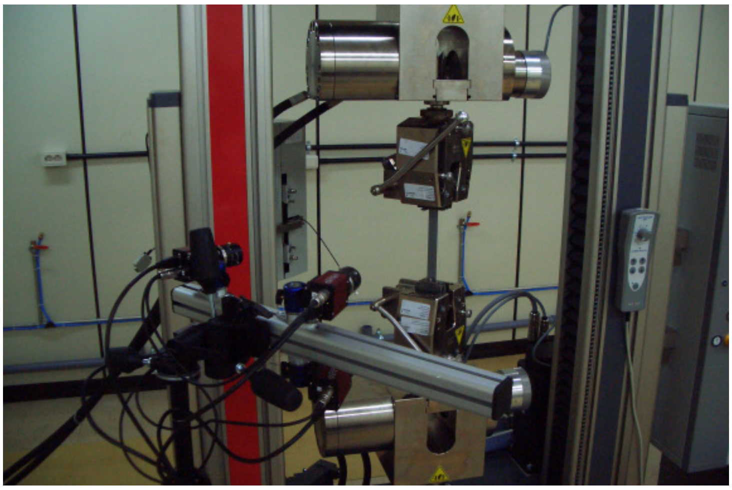

Figure 4. *Setup of a tensile test using in-process recording techniques for strain analysis*

Of course the application of such in-process recording techniques is also very interesting for the tensile test. One question was: Do these deformation stopping areas also appear during the local necking in the tensile test? In figure 4 is shown the testing setup with a tensile testing machine of Zwick and the *AutoGrid*® *vario* measuring device at POSTECH in Korea.

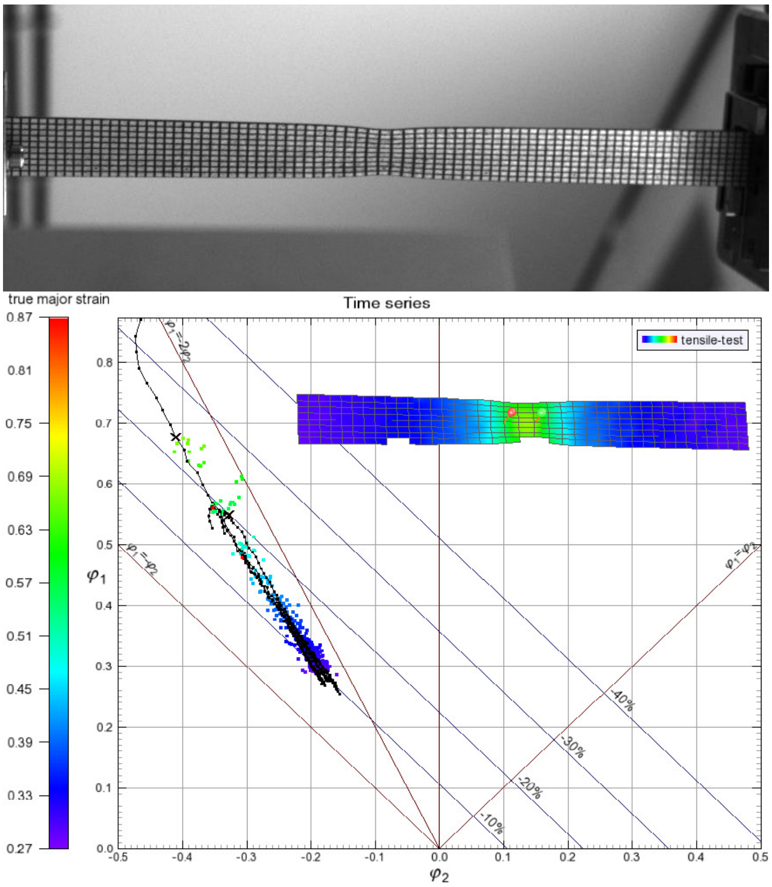

Figure 5. *Results of a tensile test of DC04 before start of local necking with strain paths*

In short: Yes, also in the tensile test of a ductile material (DC04) these stopping areas on both sides of the necking area 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. In the shown two strains paths of points in the neighbourhood of the local necking area the effect of the stopping area is visible very clearly.

3. STRAIN ANALYSIS ON DEFORMED SHEET METAL PARTS

3.1. 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 demands the *AutoGrid® compact* device (see figure 6) was designed.

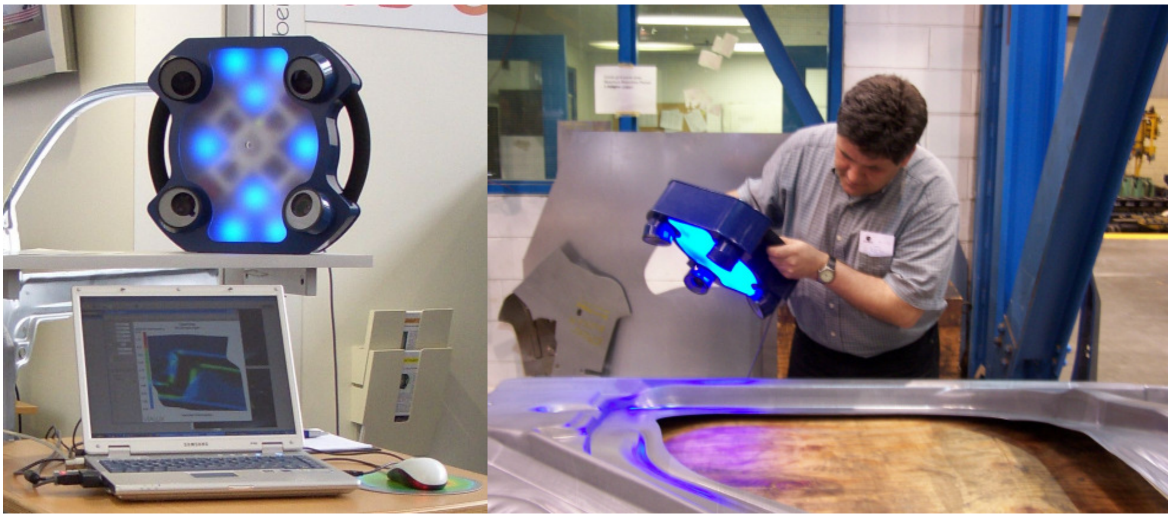

Figure 6. *The AutoGrid® compact device connected to a laptop and in action with operator*

This *compact* device for handheld use in a robust housing fulfils a lot of functions. At first there are the 4 fixed cameras for the photogrammetrical measurement. Together with the used high quality optics of *Schneider-Kreuznach* they are optimized to cover the grid markings also on complicated surfaces very easy in one shot (one picture of each of the 4 cameras). Because the cameras and the optics are rigidly placed in the compact device housing measurements are possible without any setup and calibration stages.

The pixel resolution of the 4 cameras is optimized for the typical needs but it is also adaptable to any special customer needs. A typical value for a good setup is approximately 10 (or more) pixels between two grid markings (line crossing points of a square line grid). A marking itself (a grid line) should have a width of 3 or more pixels. So it is possible to measure in one shot up to much more than 10.000 grid markings in a very short time (3-5 minutes) over a measuring volume of up to 480*360*150 mm³.

Additionally the compact device includes some switchable illumination LEDs and the cameras can be controlled by the used firewire interface from the software. So the operator is able to adapt the system to all the different lightning conditions happened in the real use.

For ease of the handheld use the *compact* device includes a laser triangulation with two laser pointers. If the two laser beams come together on the marked part in the area the operator wants to analyse than this is the right distance and position for the measurement and the laser points show the centre of the 4 camera images. To start the image recording the operator pushes the recording button on the compact device (like with a photo camera). Of course to have the capability of handheld use all 4 cameras have to be synchronized.

The *compact* device is connected to the laptop PC by a standard firewire cable with a standard length of 4.5 metres. With this single small cable connection the compact device is controlled from the laptop PC, it gets its needed electricity power and the recorded images are transferred to the PC.

The compact device is delivered with a safety case that fits into a box meeting the international flight cabin hand luggage dimensions. So together with the system laptop PC the *AutoGrid®* *compact* system is really mobile.

3.2. Automatic stitching together using additional coded markings

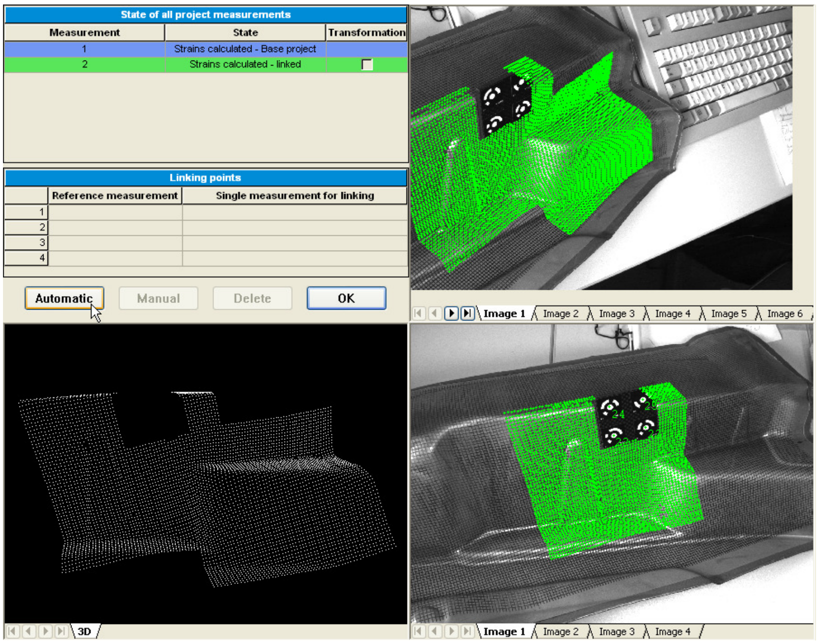

Figure 7. *Screenshot of the AutoGrid® software during automatic stitching together*

Often the strain analysis results should be presented not only over an area recorded by one picture set but over a larger area. So for perfect post processing it is necessary to stitch the measured grid point clouds including the strain results together into one large linked measurement. One way to make this easier and faster is the use of additional coded markings mounted on the analyzed part during the image recording. In figure 7 a screenshot of the *AutoGrid®* software shows an example of this process using the displayed coded markings.

4. ACCURACY TEST FOR STRAIN ANALYSIS SYSTEMS

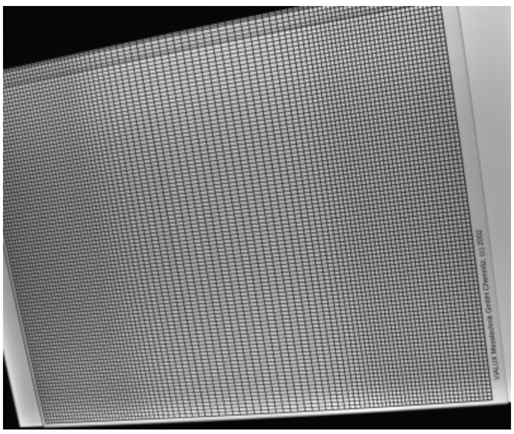

Figure 8. *Micro precision testing grid for optical strain measurement accuracy tests*

The optical strain measurement accuracy of strain analysis systems can be checked with the help of a defined distorted micro precision testing grid representing defined deformations. So the *AutoGrid*® systems are checked with a testing grid on a glass panel. The markings of this testing grid were made with an accuracy of ±2µm. The basic grid spacing is 2mm and the grid models a major engineering strain of 0-100% and a minor engineering strain over the whole grid area of 0% (see figure 8). So the optical strain measurement accuracy can be checked not only on an undeformed grid but also for varied large deformations.

The following figures shows example results of such an accuracy test. In figure 9 the major strain results are shown over the whole area and along the displayed intersection. On the left and on the right side the correct values for the major strain of testing grid are "0.0" and then it changes up to a value of 100% in the centre of the testing grid.

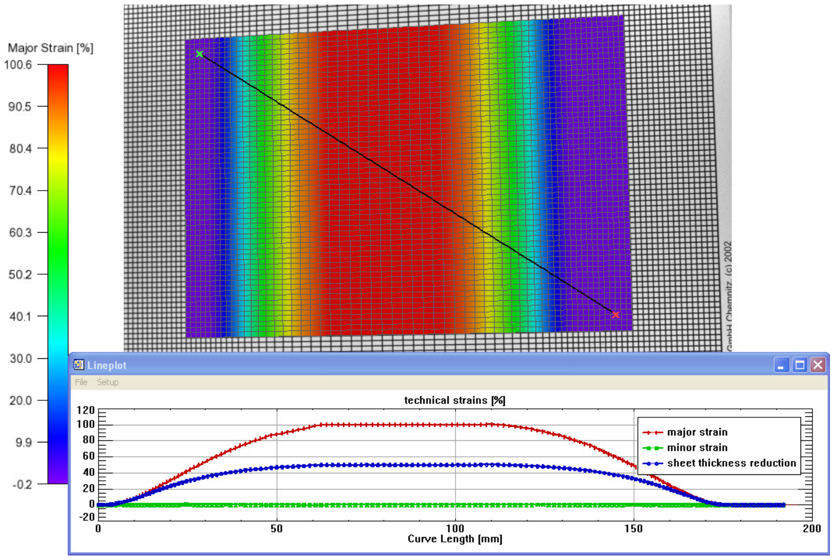

Figure 9. *Measured strain distribution on the testing grid*

The correct value of the minor strain over the whole area of the testing grid is "0.0". So all deformation different from "0.0" in the measuring results of the minor strain is directly a strain measuring inaccuracy. These results are shown in figure10 over the whole area and also along the displayed intersection.

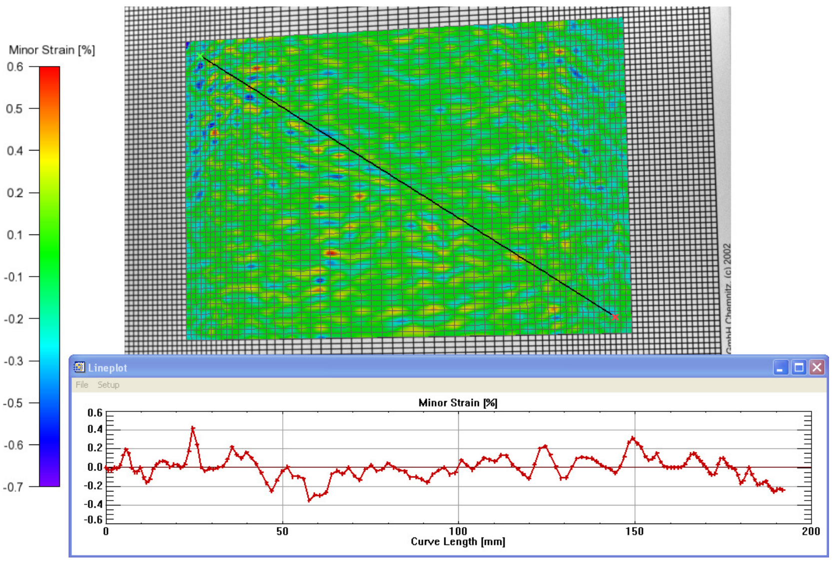

Figure 10. *Measured minor strains of the testing grid*

The standard deviation of the evaluated inaccuracy in this example over all points is lower than 0.1% engineering strain. This small value is valid for the undeformed area of the testing grid as well as for the area with large major strains. The maximum of inaccuracy is ±0.7%.

Figure 11 shows the major strain results over the whole area and along the displayed intersection in the 100% major strain area. The results have a very small scatter around the mean value of 100% and the maximum of inaccuracy is also in the range like for the minor strain shown in figure 10 (±0.7%).

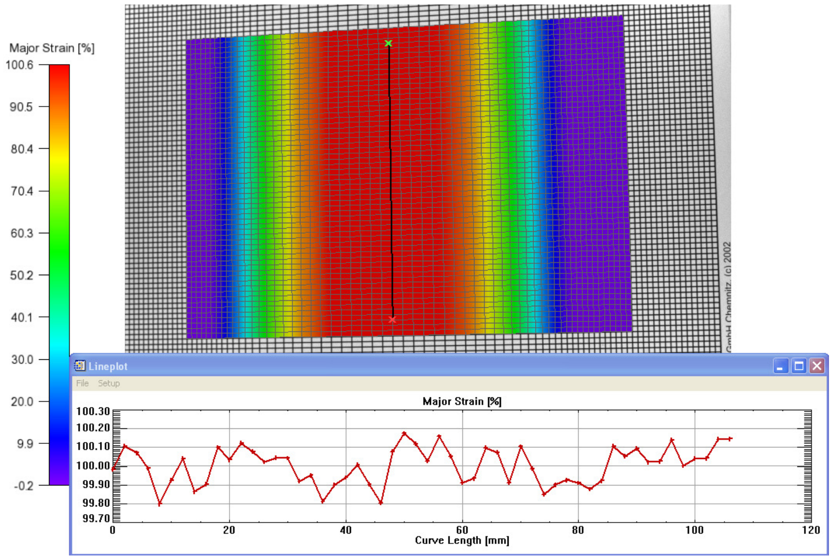

Figure 11. *Measured major strains of the testing grid*

For the most of the strain analysis applications such an optical measuring accuracy will be sufficient. Of course also the applied grid markings should fulfil high demands on the accuracy. The real strain measurement accuracy in total also depends on the quality and contrast of the grid markings after deformation. And not to forget: Of course there is also a natural scatter in the deformation process itself.

5. REFERENCES

References should be quoted in the text using consecutive numbers in square brackets, alternatively, as shown here [1], or [2, 4], or [1-3]. At the end of the manuscript, they should be cited as follows:

[1] P. Feldmann and 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.