Proceeding of the 15th ME-NETT conference

Determination of Metal Forming Press Accuracy Using a Laser Based System

DIpl.-Ing. Jan Welkert, Dr. Kusol Prommul
Department of Tool and Materials, Faculty of Engineering, King Mongkut's University of Technology Thonburi
Suksawads 48, Tungkru, 10140 Bangkok, Thailand
Tel: ++66 2 470 9213, Fax: ++66 2 8729080, E-mail: jan.wei@kmutt.ac.th, kusol.pro@kmutt.ac.th

Abstract

The elastic behavior of forming and stamping presses influences the dimensional accuracy, tool life, reliability and stability of the process. Characteristics and parameters that describe the elastic behavior under load are much more predictable than those determined under non-load conditions such as parallelism of bolster and slide face. Following a detailed description of both characteristics and parameters of press machines, their useability for the man in the workshop is explained. The Laser-measurement system for determination of such characteristics and parameters is introduced and the specific advantages are emphasized. By use of a case study, the necessary procedure for determination of the required information using the Laser system is then outlined.

Rising quality requirements and increasing automation lead to increasing demands upon precision of the workpiece. The movement of the tools and the movement of the slide determine the accuracy of the product. Furthermore the slide-movement has a decisive influence upon tool life, examples for this are extrusion tools and those used in cutting and blanking processes.
In a homogeneous deformation process the punch submerges into the bottom die, centric and without any tilting, until the required shape of the workpiece is achieved. After forming the workpiece the punch slides back, retracing exactly the same path.
In reality however the punch does not travel along this ideal path. Due to the results of eccentric loads, both tilting and vertical deflection of the slide and the upper tool occurs.

Characteristics of press machines

The metal forming machine must guide the tooling onto the workpiece accurately. Deviations from accurate machine guidance cause positional errors on the tool parts, resulting in corresponding errors in the workpiece. The positional error due to initial contact is caused by geometric inaccuracies of the machine in the unloaded state. During loading the elastic deformation of the machine causes the tooling to drift. Hence we must take a distinction between the accuracy characteristics of a metal forming machine both in the loaded and in the unloaded states. It should be remembered however that accuracy characteristics in the loaded state are much more relevant for the workpiece accuracy [1].
When measuring the accuracy values of press machines, the use of a standard coordinate system such as that suggested in DIN 55189 [2] is advantageous. The point of origin of the three-dimensional coordinate system X, Y, Z is in the middle of the unloaded Presstable. A, B and C nominate rotations around axis parallel to X, Y and Z. The direction of the rotation is positive when looking into the positive direction of the axis the direction of the rotation is clockwise (fig. 1).

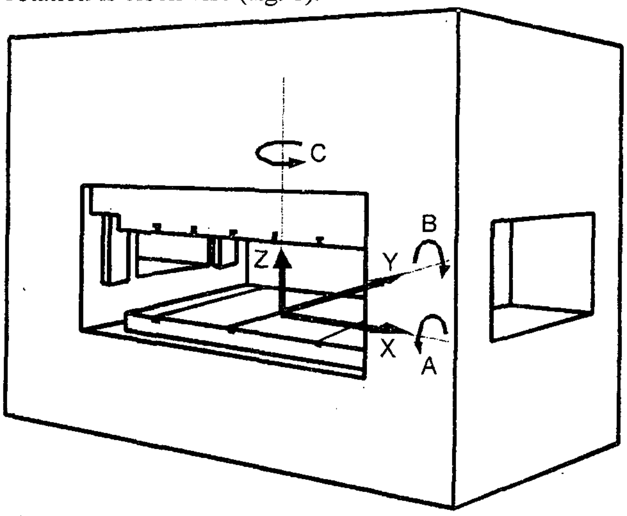


Fig. 1: *Coordinate system [2]*

For the particular degrees of freedom there is a general interrelationship between effect (deflection, tilting) and the triggering force or moment.
The principle characteristic of a deflection- or tilting function can be divided into two parts. Initially, applying load leads to a primary effect that is a result of rigid body displacement (clearance, joints). Small changes in force give rise to large changes in travel. When play is reduced, a linear interrelationship between load and effect can be observed. For this elastic phase

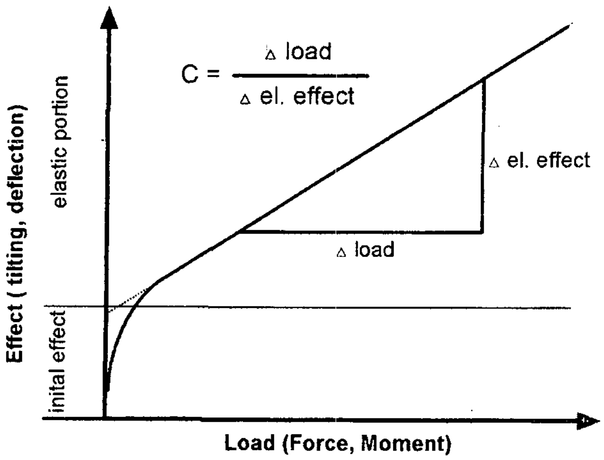


Fig 2: *principal characteristic of the effects of tilting and deflection*

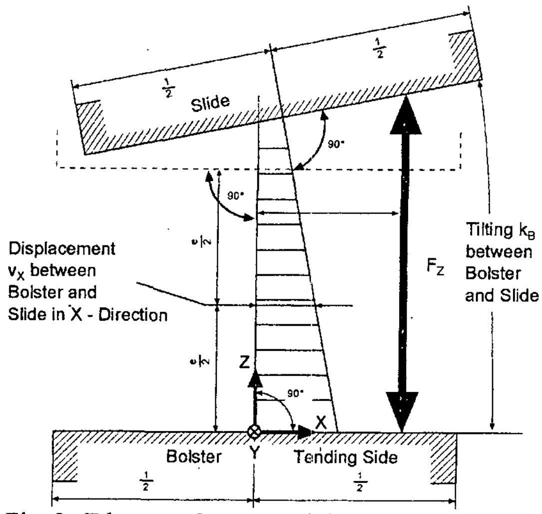


Fig. 3: *Tilting and vertical deflection*

a spring constant *C* can be calculated. *C* is the reciprocal value
of the slope of this section. Fig. 2 shows the principal characteristic of the effects of tilting and deflection.

Tilting between slide and bolster

Tilting *k* Is defined as the slope between slide face and bolster face as shown in fig. 3. The tilt value is In contrast to vertical deflection not dependent upon position along the z-axis. Absolute values can be compared directly. The moment acting on the slide mainly influences tilting. The unit for tilting is [mm/m]. Tilting is displayed as a function of the force.

The characteristic parameter describing the rigidity of the machine against tilting is the spring constant $C_{kA/B}$ this can be calculated using the following formulae:

$$C_{k_B} = \frac{\Delta F_l * r_X}{\Delta k_{el_B}} \quad (1)$$

$$C_{k_A} = \frac{\Delta F_l * r_Y}{\Delta k_{el_A}} \quad (2)$$

Displacement between slide and bolster

Displacement $v_{X/Y}$ between slide and bolster is the distance between the mean perpendicular of the slide and the mean perpendicular of the bolster under off-center load (fig. 3).

The displacement $v_{X/Y}$ is a function of the height above the bolster face. Displacement is displayed as a function of the force and is evaluated at half the height between bolster and slide.

The characteristic parameter describing the rigidity of the machine against vertical deflection is the spring constant $C_{vX/Y}$. This can be calculated using the following formulae:

$$C_{vX}(Z) = \frac{\Delta F_l}{\Delta v_{el_X}(Z)} \quad (3)$$

$$C_{vY}(Z) = \frac{\Delta F_l}{\Delta v_{el_Y}(Z)} \quad (4)$$

Measurement of accuracy

For determination of these effects different measuring methods have been developed. That suggested in DIN 55189 is shown In Fig. 4, whereby load is applied by a hydraulic cylinder.

For hydraulic presses the drive system of the machine is employed and the hydraulic cylinder replaced by a support. The force transfer must be devoid of any lateral forces whilst influences of tilting and deflection behavior of the machine must be kept to a minimal. This can be achieved by use of a cardanIc spherical cap. The load applied should be not less than 50% of the machines nominal force. The eccentricity where the force is applied is 10% $l_{X/Y}$ where l is the length of the press table. Four gauges measure dimensional differences between the slide and the press table at each corner of the bolster. Tilting values can be obtained from the differences between two gauges on one axis. To measure deflection, gauges W5 and W6 are used. They are fixed to a frame that rests on the press table and work in horizontal direction.

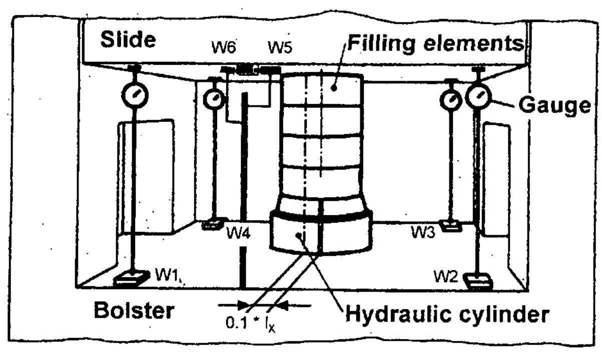


Fig. 4: *Measurement of tilting and vertical deflection [2]*

This suggested method has a number of disadvantages. Tilting and deflection can only be measured static and with the slide at BDC. Horizontal deflection is faulty. All the gages are mounted directly to the bolsterface by long stands. When load is applied, the elastic deformation of the bolster leads to large errors in the measurement caused by the long lever-arm of the stands.

Also presses are loaded with high forces; therefore finding a fixed reference plain is a major problem.

Lasersystem - working principle

Reference of the Lasersystem is a laser beam, absolutely straight and almost infinitely long. The laser-source is fixed to the press-frame and the beam impinges on a Sensor that is mounted to the moving test object. In the sensor are located two position sensitive detectors (PSD's). These detectors acquire the position of the laserbeam in the X - Y plain. A 45° beam splitter splices the beam. After a short distance the beam meets PSD 2; one coordinate is reflected onto the detector by the beam splitter. The remaining beam travels on to PSD 1, placed at a greater distance from the beam splitter. By taking measurements, one beam compared to the other, tilting and horizontal deflection can be determined. A simultaneous movement of the laserbeam on both detectors shows a horizontal deflection of the sensor (D1 = D2). An opposed or different movement of the laser-spot on the PSD's indicates tilting (D1 ≠ D2). Every detector delivers one X- and one Y coordinate, hence horizontal deflection v_X and v_Y and tIltIng k_A and k_B can be determined with one sensor.

Every part in the force-flow of a press features elastic deformation under load. As mentioned, this is an important issue when fixing measurement references before measuring the accuracy of the machine. Under load even extremely small angular deviations at the attachment point of the laser-source and adequate length of the laserbeam can simulate big deflections of the test object.

To compensate for this, two identical systems are mounted symmetrically to the press. The elastic effects on both systems are in opposite directions and therefore counterbalance one another. If the machine is centrally loaded measurement errors are compensated; off center measurement error is reduced. Additionally this configuration enables determination of possible twisting of the slide around Z-axis (tilting k_C).

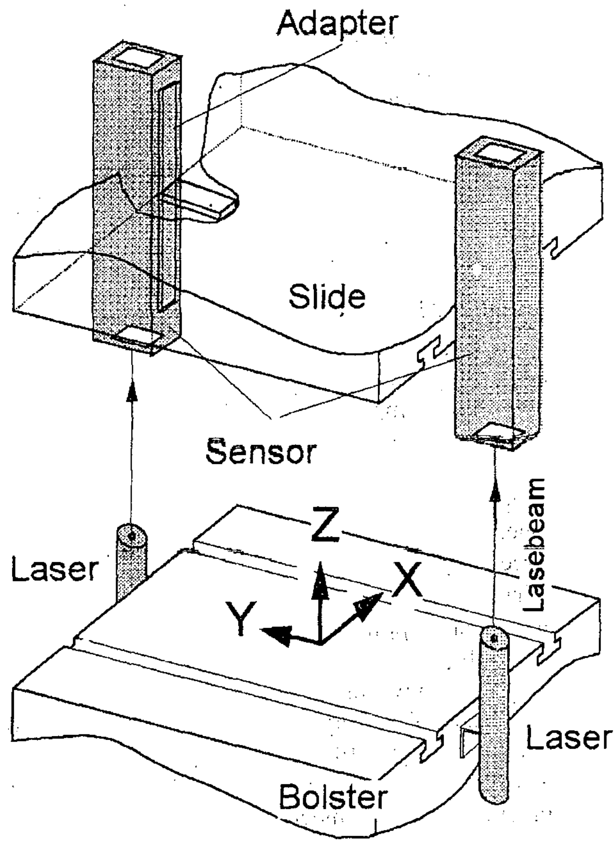


Fig 5: *Lasersystem for determination of press characteristic under static and dynamic load [3]*

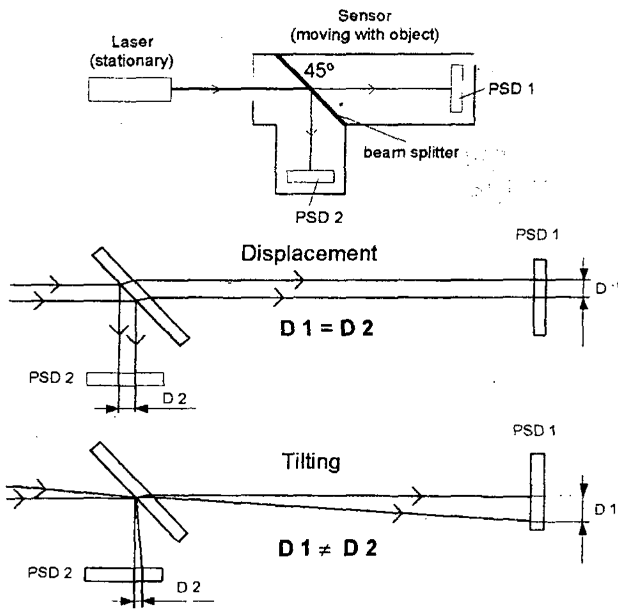


Fig. 6: *Determination of tilting and vertical deflection using the signals from one sensor*

A laserbeam has almost infinite length. Hence determination of slide movement and the elastic effects can be done over the complete stroke of the press.

For operation of the system a complete software solution consisting of different modules has been developed. A module for adjusting the system after mounting it to the machine enables the user to setup the device easily. A second module is for evaluation and interpretation of the results.

Parameters that can be determined with the system including measuring range and obtained accuracy are shown in table 1.

Table 1: *Parameters of Laser system*

	k_A / k_B [mm/m]	k_C [mm/m]	v_X / v_Y [mm]
Range	± 16.25	± 5	± 3.25
Deviation	0.1	0.04	0.05

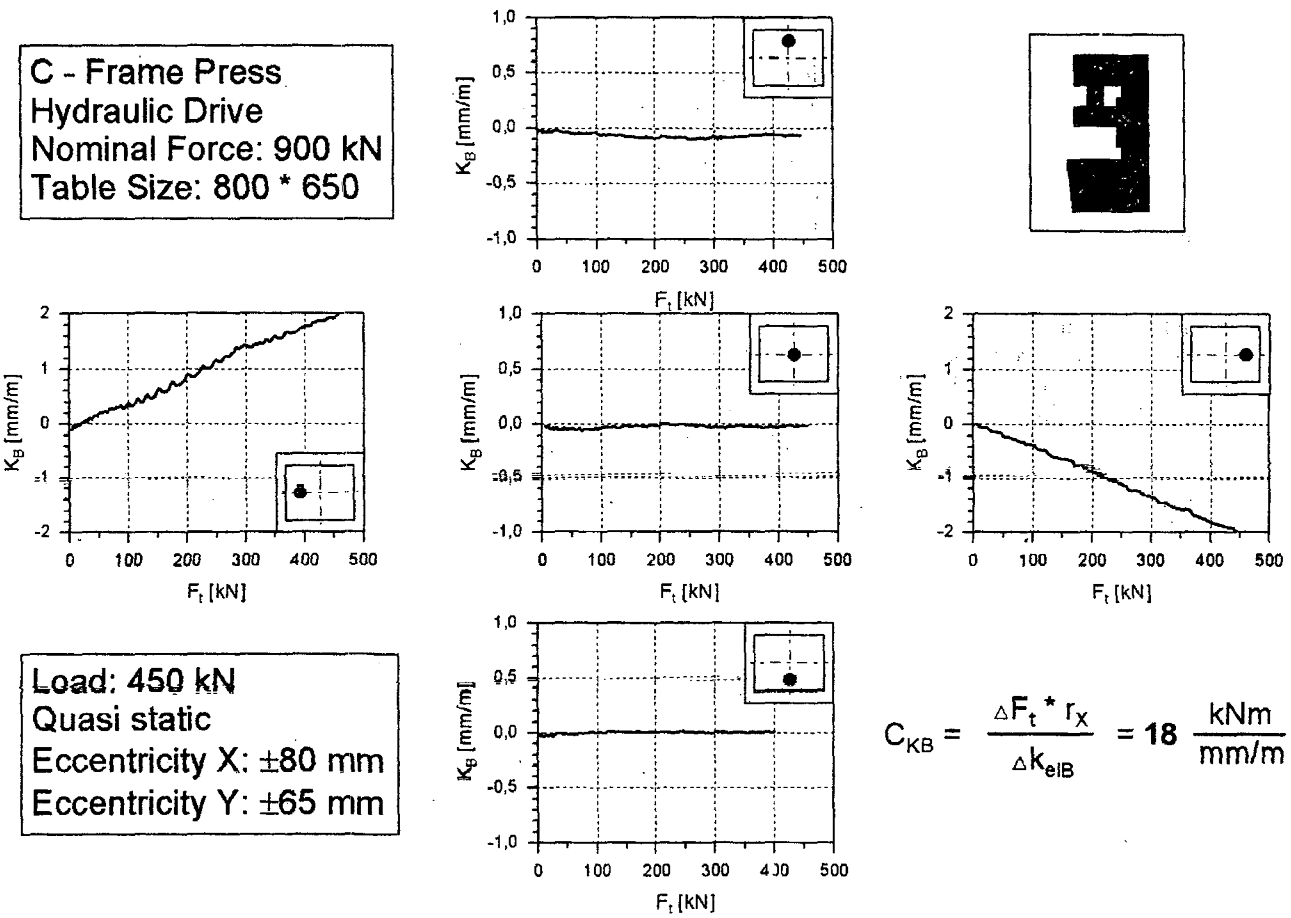
Example for application

As an example an accuracy test on a C-frame press is shown. The press has a hydraulic drive and a nominal force of 900 [kN]. Tablesize is 800 * 650 [mm]. The load is applied with the drive system itself and a cardanic spherical cap is used to guarantee elimination of lateral forces and to keep the influence on tilting and deflection behavior of the machine to a minimum. Off-center load is quasi static applied in ± X , ± Y and the center of the press table.

Fig. 7 shows the curves evaluated for k_B as a function of the load for every single loading position. At center load there is no tilting of the slide around Y-axis as expected. Also when the press is off-center loaded on ± Y direction there is almost no tilting. When load is applied on ± X the slide moves in positive or negative B-direction. Elastic behavior of the press is symmetric. This shows for example, that the clearance of the guidance system, which is situated at the back of the slide, is correctly adjusted on both sides. Initial effects are zero. This is an indicator for tight adjustment of the guidance system but also typical for hydraulic drive systems where initial effects are generally small. The characteristic parameter C_{kB} can be calculated from these two curves. Knowing this value enables the user for future operations to precalculate absolute values for tilting at given loads.

In Fig. 8 the curves for k_A as a function of the load are displayed. For all positions the tilting is in negative A direction except for loading on +Y the direction is negative A. Maximum values for tilting k_A occur during loading on –Y. This is the weakest position;

Fig. 7: *Tilting k_B as a function of the force*



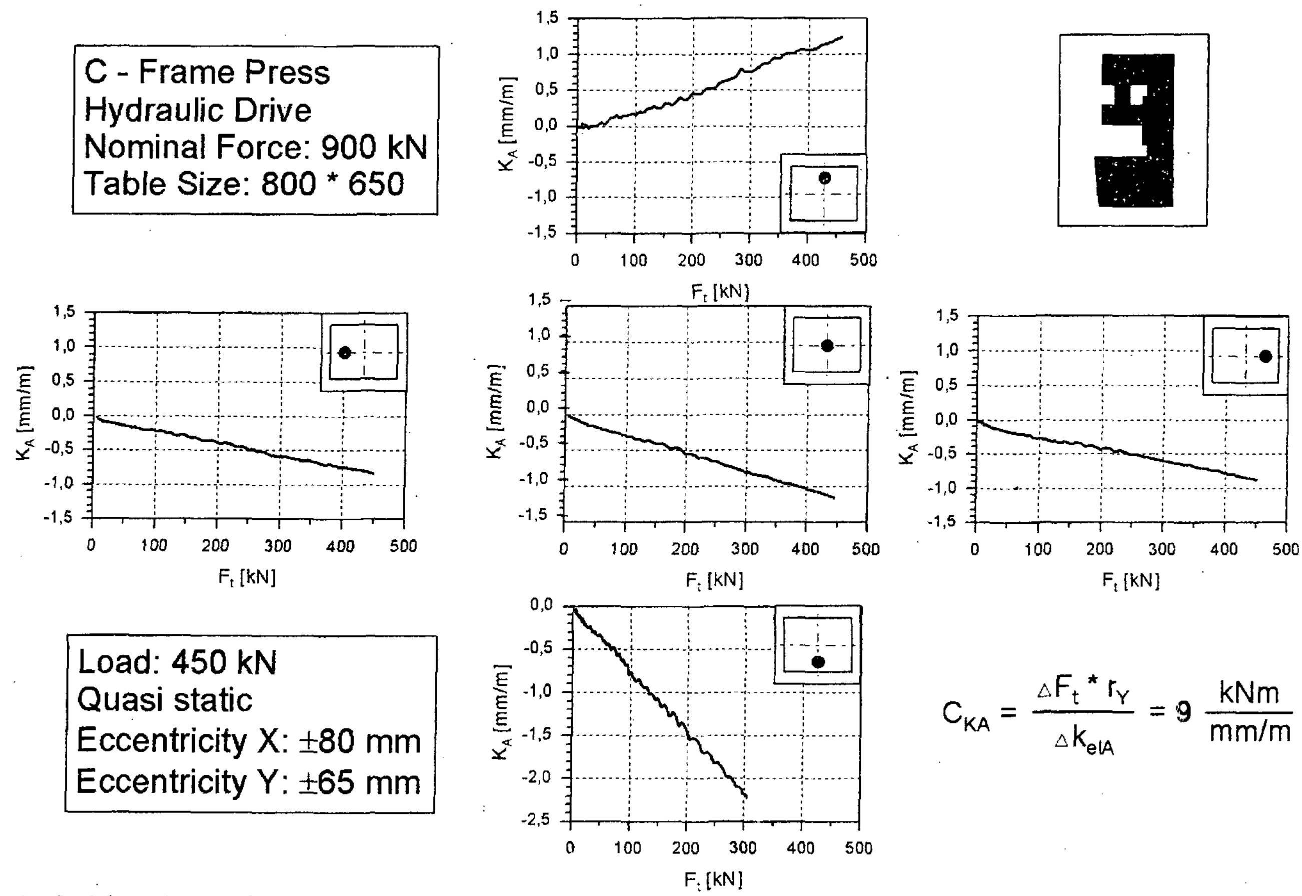


Fig. 8: *Tilting k_A as a function of the force*

hence the value for C_{kA} is calculated for that point. The major weakness of the C-frame design is clearly visible. Even under center load the slide tilts in negative A-direction. At this particular press it is possible to avoid tilting around X-axis. The test shows for loading on positive Y a positive tilting and for loading in the center a negative tilting. Consequently a point between these two exists where instead of tilting pure vertical deflection occurs. This knowledge enables the user to avoid problems caused by tilting by simply moving the center of Force of the tools used on this machine to this point.

Conclusion

Determination of press machines characteristic parameters is an important issue. If the user of the machine is aware of these parameters, he can take them into account when designing tools and assessing tolerances of workpiece to be produced on the machine. Further more the machine user will be capable of analyzing problems during manufacturing by monitoring the characteristic parameters of the machine.

The Laser-based system for determining characteristic parameters of press machines under static and dynamic load offers various advantages compared other existing measurement systems.

The components are mounted in front of bolster and slide; the tool area is therefore still fully accessible. In contrast to inductive travel sensors or gauges, the measuring range is not limited, the movement of the slide can be monitored over the complete stroke. By using two sensors, errors due to elastic deformation of the press table can almost be eliminated. By using this system dynamic tests are possible which give significantly different results to static ones and are also more practice oriented.

The system opens new perspectives for accuracy-controlled presses. Movements of the slide can be monitored during production and fed back as correction variables into the control system.

Reference

[1] Lange, K.: Handbook of Metal Forming, McGrawHill Book Company (1985), Chap. 9

[2] DIN 55189 Part 1 and 2 (in german)

[3] Freiherr, T.; Wagener, H.-W.: Lasersystem for determination of accuracy values (in german), Blech Rohre Profile (10/1997)