New operating principle for materials testing machines

by Winfried Markowski

A common problem in materials testing is the reduction of unwanted effects caused by the testing machine which stores energy und suddenly releases it during the fracture of the specimen. This article presents a method of improved testing using a force shunt system. The technique is regarded as complementary to traditional methods.

Usual principle and its disadvantages

The traditional testing machines for investigating materials are constructed according to an operating principle where they form a mechanical series circuit arrangement for the flow of force. This operating principle is shown diagrammatically in **Fig. 1** for a tensile testing machine. This series arrangement contains elastically deformable components, including the driving mechanism from which the force originates, the sample with its clamping elements through to the force reaction point on the machine frame. Due to their elastic properties, these components must be considered as representing stores of energy during loading. Therefore on account of the operating principle, the parts of the machine included in the mechanical series circuit become sources of force, because of the elastic energy stored in them. This operating principle, which causes loading and unloading of both the sample and testing machine simultaneously during a test, has well-known disadvantages in the testing process:

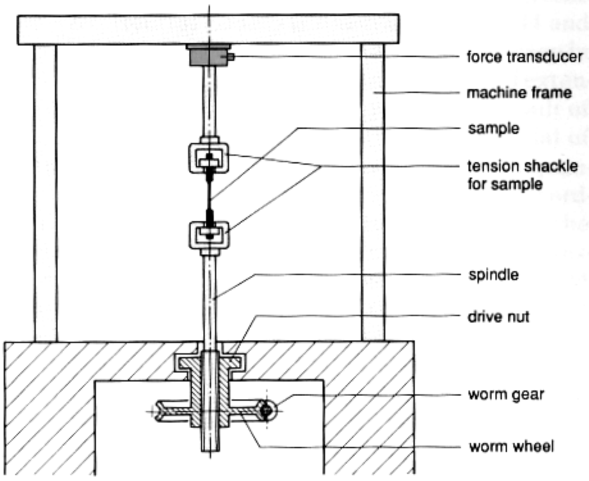

Fig. 1: Diagram showing the principle of a normal material testing machine which produces the force mechanically via a spindle

- During spontaneous changes in elastic properties, the sample is deformed still further very suddenly and uncontrollably by the released elastic energy. This can lead to unintended and non-reproducible microstructural changes, such as for example, microcracks in ceramic samples or exceeding the apparent yield point for steel samples.
- A drive speed which is specified as being constant does not necessarily produce a constant deformation rate, because the resilience ratio between the sample and the testing machine changes depending on the force, as do the proportionate deformations.
- Force-dependent unsymmetrical properties in the deformations within the testing machine, which can never be completely eliminated, lead to unwanted bending effects and therefore also to disturbing bending loads on the sample. The sudden total removal of the load during the fracture of the sample can only serve to increase these effects and produce other negative influences over a period of time.

Efforts have been made to avoid these disadvantages for almost as long as testing machines have been used for material testing. Basically, there are two possible ways of solving the problem. One involves the minimization of the disadvantages while retaining the operating principle, but with this method the effort required increases exponentially as the optimum is approached. With the other method an attempt is made to change the principle with the intention of obtaining the goal directly with the minimum of effort.

Previous attempts at improvement

Previous efforts at reducing the disadvantages outlined above while still retaining the basic principle mainly involved the frame and the drive of the testing machine including the controller design. With regard to the mechanical design, attempts were made mainly to increase the stiffness of all force-transmitting parts of the testing machine and this sometimes led to substantial increases in cost. Further developments involving the drive included complex designs with servo-hydraulics or four-quadrant operation for fast speed of response and high performance.

The introduction of deformation control in testing machines was a consequence of the requirement of specifying the deformation as the independent variable and the force as the dependent variable. Although at first sight these measures appear to give a substantial improvement, they do not fulfill the demands made in one important respect. The control of displacement is bound to be too late for spontaneous changes in the sample's microstructure, because a deviation from the reference value is only present as a control signal for a possible correction after a change in strain has taken place. This is provided that the response threshold for the controller has been exceeded. The drive, which also acts as the final control element, must compensate not only for the magnitude of the change in the sample's length, but also for the magnitude of the change in the spring displacement of the testing machine due to the change in force. The mass acceleration required here causes additional delays in the process. The corresponding value for the force is also seriously affected, because the return from deformation during this corrective process results in the relieving of the load on the sample, but this means removal of force according to elastic relationships. For all the non-elastic changes of shape, this type of release after the exceeding of a value signifies a substantial undercutting of the corresponding force value (e.g. erroneous lower yield point).

The application of a direct displacement source, which defines the displacement as a quantity without a controller, would basically eliminate the disadvantages described above. Through the introduction of this novel operating principle, which is described below, the disadvantages of the traditional testing machine can be avoided.

New principle with direct setting of displacement

The objective of the new principle is to exclude the force source effects of the drive as well as the deformation energy stored in the machine frame and in the parts used to transfer force to the sample. This is achieved by placing a stiff force shunt, adjustable for length in parallel with the sample. This force shunt, consisting of a frame and which has an adjustable working length, operates exclusively as a source of displacement for the deformation of the sample and it can be regarded as a complementary principle to traditional testing machines.

With this new principle the direct setting of displacement is made using the length adjusting device on the force shunt. The principle is illustrated diagrammatically in **Fig. 2** for a tensile testing machine. The frame arranged as a force shunt is shown which hydraulically supports the force of the drive. The length adjustment on the force shunt is obtained through the hydraulic fluid. It is then possible for example to release a defined quantity of the fluid used to transfer the force to the shunt frame in order to obtain a defined piston displacement and therefore a defined sample deformation. This displacement is measured by an inductive displacement transducer. In this design the testing machine itself only has the function of an external source of force which carries out the work of deformation. All the force-dependent effects of the testing machine are eliminated during the test due to the constant behavior of the external force. Therefore, high demands are no longer made on the stiffness of the machine and its drive. As a source of force, the "infinitely soft" testing machine, which is represented in Fig. 2 by a machine with loading weights, is a practical method. Alternatively loading can be made with a lightly tensioned spring. In comparison to servo-hydraulics or to four quadrant drives, these sources of force are unsurpassable in simplicity.

Using the new principle, changes in the deformation resistance of the sample including its fracture, only lead to a rearrangement of the flow of force between the sample and the shunt. The force taken up by the sample is extracted from the force shunt and vice versa. The sum of both of these remains constant. **Figure 3** illustrates an initial laboratory prototype of a testing machine operating on this new principle. The amount of effort required for the realization of the principle is relatively low. **Figure 4** illustrates in a close-up the shunt frame with the hydraulic elements, the sample clamping arrangement and the transducer for the acquisition of the measured quantity. The W 10TK Inductive Displacement Transducer included in the equipment to measure the displacement can be seen in the photograph along with a U 2A Force Transducer which has a nominal force of 10 kN.

The result of a test carried out with a directly defined deformation using the new testing machine is shown in

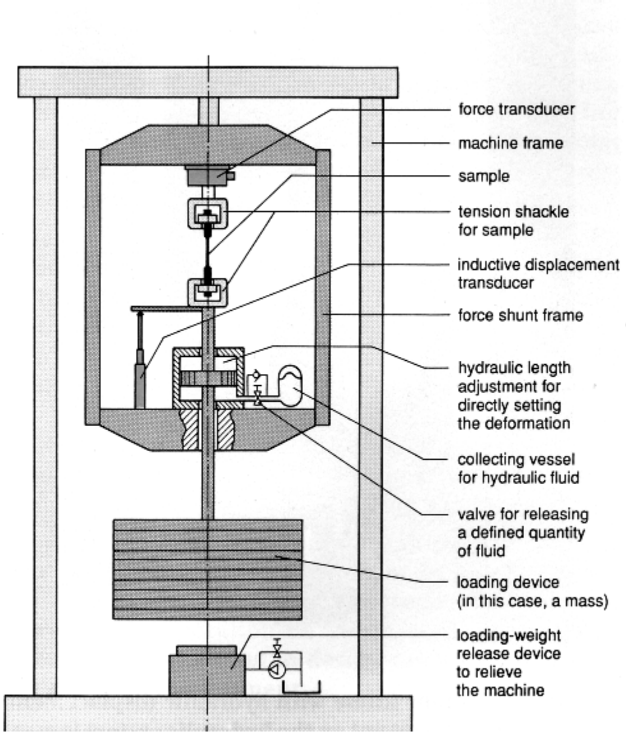

Fig. 2: Diagram showing the principle of the force shunt

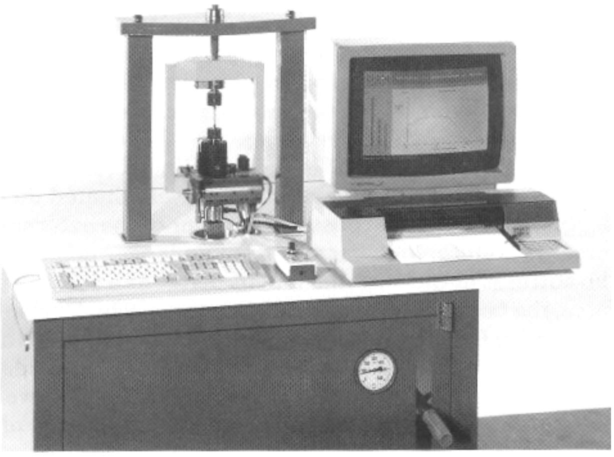

Fig. 3: First working laboratory prototype of a testing machine based on the force shunt principle

Fig. 5. This force-deformation curve illustrates the advantages of a direct source of displacement (without any controller!). In the range of decreasing force, i.e. decreasing deformation resistance of the sample, the pauses in the progress of the deformation at A, B and C are particularly impressive. In this region of decreasing force, a traditional testing machine would further deform and perhaps fracture the already constricted sample due to resilience even if the drive is switched off.

With this new method, the procedure can be stopped at any point. In order to demonstrate the principle, the deformation was stopped at A, B and C each for about one minute. At A and B an intermediate deloading and return from deformation were able to be made and at C the highly constricted sample was then able to be relieved of its load immediately before fracture and taken out of the machine. It is worth noting the good reproducibility between the two intermediate deloadings at A and B.

Figure 6 shows the sample after this tensile test which was interrupted shortly before fracture occurred. The highly constricted section can be clearly seen as well as the changed surface in this section of the sample.

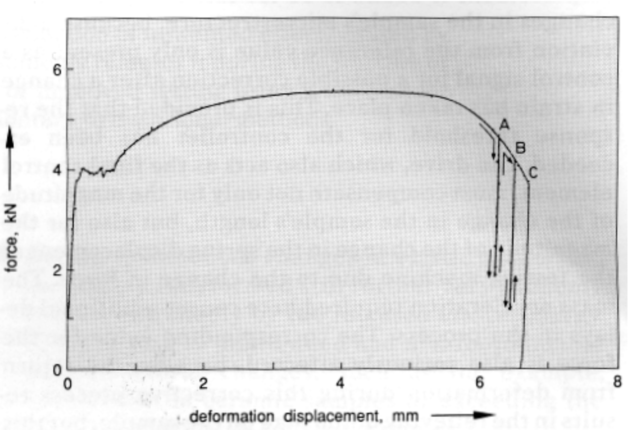

Fig. 5: Force-deformation curve for a tensile test obtained with directly defined deformation on a steel sample taken up to shortly before the start of fracture

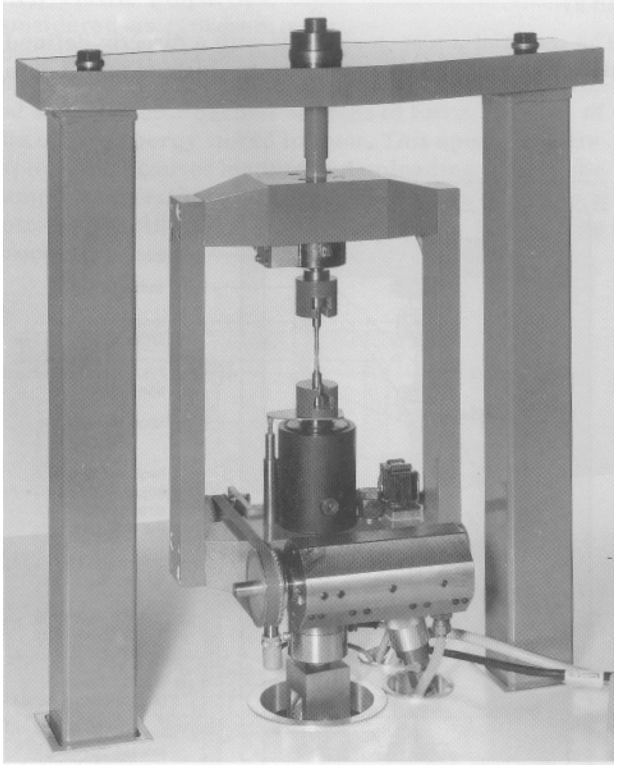

Fig. 4: Force shunt frame with hydraulic displacement regulator. Displacement on the hydraulic system is measured with a W 1OK Inductive Displacement Transducer and a U2A/10 kN device is used for force measurement

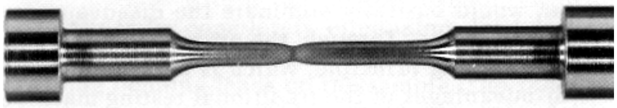

Fig. 6: Photograph of the sample from the test in Fig. 5. The advanced state of constriction is apparent

The new principle can be used in the same manner for compression or torsion tests and corresponding improvements are obtained when investigating particularly brittle materials such as ceramics. Also, tests with very different speeds up to almost a shock-type process can be realized with a defined displacement and speed. This is particularly interesting when testing both plastic and metal materials.

The Federal Institute for Materials Research and Testing (BAM) has applied for patents nationally and internationally, so that licensing agreements can now be established with interested parties.

Dipl.-Ing. Winfried Markowski is with the BAM (Bundesanstalt für Materialforschung und -prüfung) in Berlin, Germany where he is head of the Laboratory for Materials Testing Machines and Calibration of Measuring Systems.