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# DYNAMIC TENSILE TESTING WITH A LARGE SCALE 33 MJ ROTATING DISK IMPACT MACHINE

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Résumé
On décrit une machine d'essai de traction dynamique de conception récente. Cette machine consiste essentiellement en un pendule qui tient un échantillon et un grand disque en acier avec un double marteau fixé à sa circonférence. Le diamètre du disque est 2000 mm, et sa masse est 6400 kg. Les échantillons sont des éprouvettes de traction de Ø 20 mm et de longueur 300 mm, ou des éprouvettes CT 15 à températures variables. La vitesse d'impact va de 1 à 150 m/s. Le procédé de couplage entre l'éprouvette et le marteau est seulement possible grâce à un asservissement de la machine au moyen de capteurs ultra-rapides et d'un calculateur. En plus des techniques de mesures classiques, on utilise une caméra à images pour enregistrer la déformation de l'échantillon pendant l'impact. La machine et ses équipements sont décrits et on présente quelques résultats préliminaires.

Abstract
A recently completed testing machine for dynamic tensile tests is described. The machine consists essentially of a pendulum which holds the specimen and a large steel disk with a double striking nose fixed to its circumference. Disk diameter measures 2000 mm, while its mass is 6400 kg. The specimens to be tested are tensile specimens with a diameter of up to 20 mm and 300 mm length or CT 15 specimens at various temperatures. Loading velocity ranges from 1 to 150 m/s. The process of specimen-nose coupling is only possible by use of a fast process computer controlling the machine via ultra-fast sensors. In addition to standard measuring techniques an image converter camera is used to register the deformation of the specimen during the impact event. The machine and various measuring and controlling devices are described and preliminary results are presented.

## 1. Introduction

The strong influence of various parameters such as specimen geometry, temperature, strain-rate, machine compliance on the shape of the $\sigma$, $\varepsilon$ -diagram, Fig. 1, is well known, cf. /1/. Concerning the strain-rate effect, the standard static safety analysis neglects strain rates higher than $10^{-3}\,s^{-1}$ under the assumption that due to the positive slope of the toughness-strain rate curve (of common materials) the static concept yields conservative results. However, if highly dynamic loading conditions have to be considered adequately, the quasi-static tendency cannot be simply extrapolated since a sudden toughness drop occurs as the loading velocity trespasses a material dependent critical value, /2/.

To produce high strain rates a variety of different testing apparatus has been designed. The working principles of these machines are based on mechanic, rotational, hydraulic or explosive energy storage. From this, the following machine designs have emerged:

- drop weight or pendulum impact testing rigs (/3/)
- spring loaded impact machines
- hydraulic testing machines using fast valves

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- explosive driven machines (/4/)
- rotating disk impact machines (/5/)

Of these, each machine has its advantages and disadvantages: drop weight testing machines attain very large sizes if high loading rates (or high impact velocities) are desired, spring loading also gives rather low loading rates, hydraulic machines are of rather limited strain rate capability and explosive driven machines produce a strongly nonlinear $\varepsilon(t)$-characteristic and thus a non-constant loading rate. Rotating disk impact machines exhibit an almost unlimited stiffness, huge potential energy storage capability, a wide range of defined loading rates and due to the large amount of energy which can precisely be measured the velocity drop during the test amounts to less than 1% /5/. Furthermore, bending of the specimen is negligible if the disk radius is much larger than the maximum expected specimen elongation.

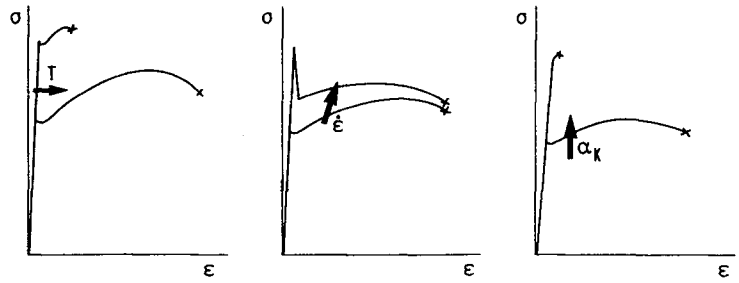


Fig. 1: Influence of temperature, strain rate and geometry on the $\sigma$ vs. $\varepsilon$ -diagram for a ferritic steel (schematic)

## 2. Rotating Disk Impact Machine

The first rotating disk impact machines date back to the thirties, /6, 7/. In 1953 the first machine of this type was installed at MPA Stuttgart. Technical data of this machine are shown in table 1. After this machine proved successful, a larger design was installed to render possible the testing of notched tensile specimens of 300 mm length and up to 20 mm dia., unnotched samples with a diameter of up to 16 mm or CT 15 specimens for fracture mechanics investigations. Due to the larger radius of the disk, bending plays an even smaller role than in the older machine. Testing at higher temperatures will be possible by use of a special furnace.

| | **old machine** | **new machine** |
|---|---|---|
| **max. disk diameter** | 720 mm | 2000 mm |
| **max. thickness of disk** | 80,9 mm | 300 mm |
| **material of disk** | St 37.21 | 26 NiCrMoV 14 5 |
| **mass of disk** | 106 kg | 6400 kg |
| **moment of inertia** | 12,47 $kgm^2$ | 2930 $kgm^2$ |
| **max. circumferential speed** | 150 m/s | 150 m/s |
| **max. stored rotational energy** | 560 kJ | 33 MJ |
| **driving motor** | 13,5 kW<br>3000 1/min | 50 kW<br>1500 1/min |
| **mechanism of specimen movement** | spring/latch | pneumatic cylinder |

Table 1: Technical data of old and new rotating disk impact machine

## 3. Instrumentation and set-up for dynamic tests

As can be taken from Fig. 2 and Fig. 5 the specimen is screwed into the lower end of a pendulum which in turn is swung towards the rotating disk by a fast air driven cylinder. Thus, a double striking nose fixed to the circumference of the 2 m disk can catch the crosshead at the lower end of the specimen and pull it apart. The crosshead can be adjusted prior to the testing in such a way that a pure tensile loading is exerted by the striking noses.

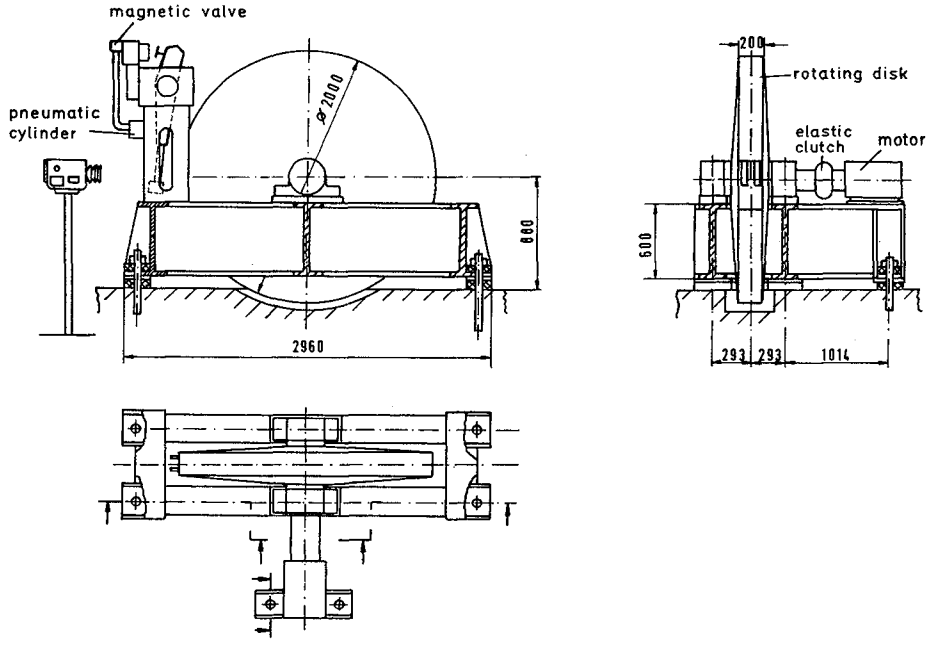


Fig. 2: 33 MJ rotating disk impact machine at MPA-Stuttgart

To start the test, the disk is accelerated up to a rotational speed slightly above the desired value. Safety requirements then ask for a turn-off of the driving engine. The computer monitors the momentary speed of the disk and will initiate the shot-in of the specimen as soon as the disk speed has slowed down due to friction to within 1 % of the prior given impact velocity.

In order to avoid specimen oscillations at the time the striking nose hits the crosshead the piston of the cylinder accelerates the pendulum which then is decelerated by a rubber damping element. Since this type of movement is rather time consuming the computer starts the cylinder-triggering process slightly ahead of time taking into account valve-delay time and pressure-built up time in the cylinder. Both amount to 58 ms, pendulum movement outside the range of the rotating nose takes another 16 ms, leaving 84 ms for the pendulum to move within hitting range, Fig. 3. Depending on the momentary speed and position of the nose the computer calculates the optimum triggering time for the whole event. As can be seen from Fig. 3, the pendulum will be for 84 ms within the reach of the rotating nose, which does not permit nose speeds above 70 m/s. For speeds above 70 m/s the pushing cylinder is positioned four times closer to the pivot of the pendulum, thus yielding a propagation time for the pendulum of 21 ms. However, with this set-up specimen oscillations at the moment of the nose-

impact cannot be excluded. In Fig. 4 the sequence of different machine signals necessary to feed the computer is shown.

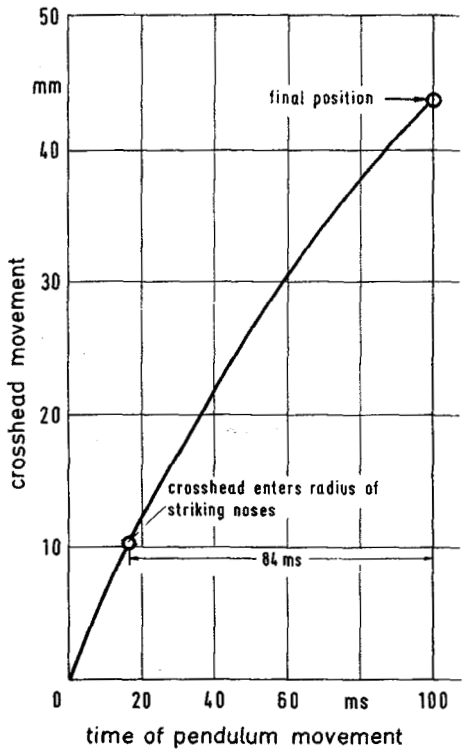


Fig. 3: Pendulum movement vs. time as measured with a fibre-optical sensor

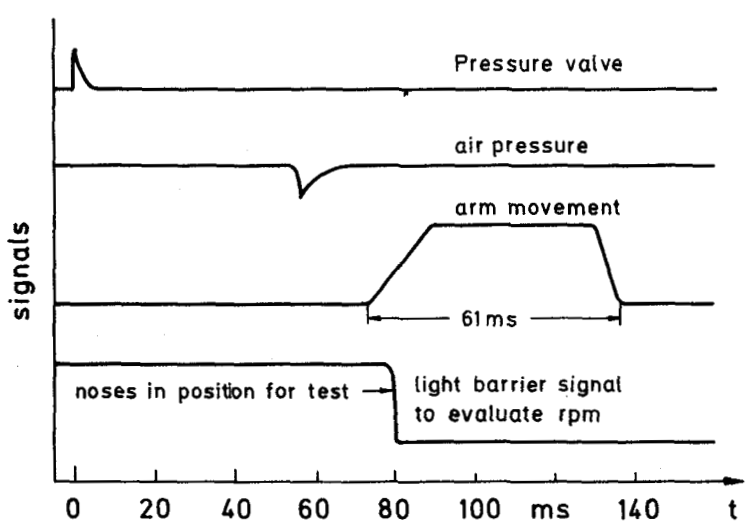


Fig. 4: Machine signals for controlling pendulum movement

As the specimen is ruptured the flight of the lower part (which is monitored by a fibre sensor system, is stopped by a bulk of modelling clay whose rheological behaviour is used to decelerate the specimen safely without the danger of having the specimen bounce back into the running noses. This may not happen, since the bearings of the wheel cannot withstand the additional momentum exerted by a mass of 1,5 kg on the circumference of the disk at these speeds.

In course of the impact event the 2 m diameter of the wheel is useful for detecting the energy flux delivered from the machine into the specimen. Since a compressional takes wave about 330 μs to spread from the stroken nose region to the opposite side of the disk, this far region of the disk moves still with its constant rotational speed while the nose section is slightly decelerated due to the energy delivered into the specimen. Simultaneous frequency measurements at these two points thus allow a direct energy determination.

The specimen may be instrumented with up to 10 strain gauges in order to derive the stress-strain relations at different locations. The moment of contact between noses and crosshead is indicated by a voltage drop induced by the noses as they couple with the specimen. In the case of CT-specimen force measurement is performed by strain gauges applied according to Krabiell and Dahl /8/ while COD-measurements are performed with a fibre sensor. Due to magnetorestrictive effects AC potential drop techniques are not always applicable.

In addition to these standard techniques micro-lattices etched onto the specimen may be fotografed using an ultrafast image converter camera. Triggering of the camera and the flash units is performed by the machine itself, Fig. 5.

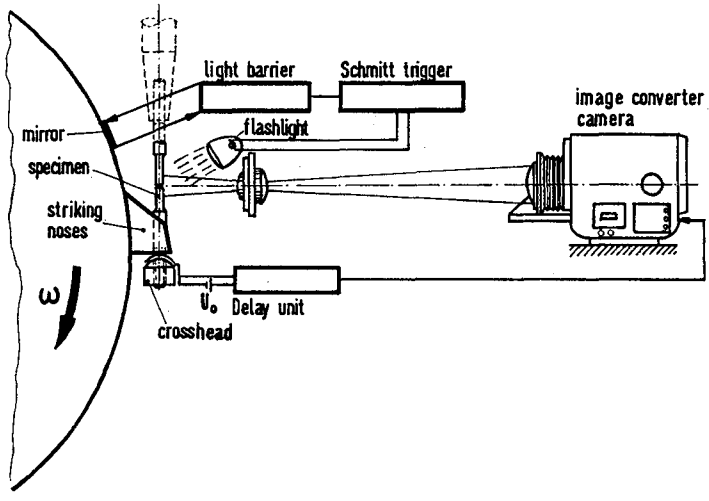


Fig. 5: Specimen with pendulum, optical set up and camera triggering system

## 4. Preliminary Results

First experiments were performed on tensile specimens made of 20 MnMoNi 5 5 steel, double edge notched tensile specimens (St 37 steel) and on two CT 15 specimens made of 20 MnMoNi 5 5. The unnotched tensile specimens revealed the expected trend of increased yield strength $R_e$ and ultimate strength $R_m$ compared with the quasistatic test while the values $A_5$ and Z change slightly, table 2.

| | $R_e$ | $R_m$ | $A_5$ | Z |
|---|---|---|---|---|
| | $N/mm^2$ | $N/mm^2$ | % | % |
| **quasistatic** | **520** | **706** | **22,5** | **68** |
| **dynamic, v=20 m/s** | **1263** | **1048** | **27,5** | **59,3** |

Table 2: Results from quasistatic and dynamic tensile tests on 20 MnMoNi 5 5

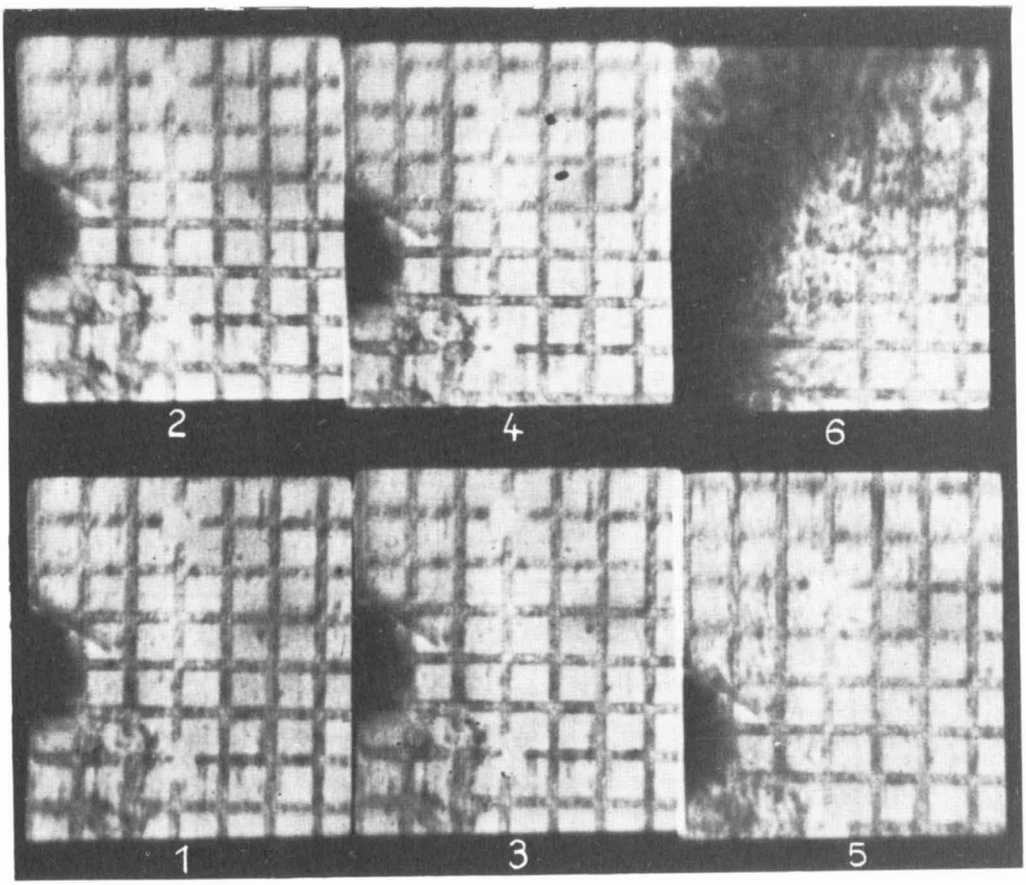


Fig. 6: Deformation around a notch (radius 0,3 mm) in dynamic test of a St 37 DENT-Specimen.
Framing Frequency 25.000 fr/s

In Fig. 6 photographs are shown which were taken on a DENT-specimen with an etched-on grid (0,17 mm distance of two grid lines) surrounding the notch tips. Notch tip radius measures 0,3 mm. Loading velocity was 16,3 m/s, framing frequency amounted to 25.000 fr/sec. Tests of this kind are performed in order to find a dynamic J-value using proper numerial calculations.

In Fig. 7 the force vs. time diagram and the signal gained from the AC potential drop method during the test of a CT 15 specimen are indicated.

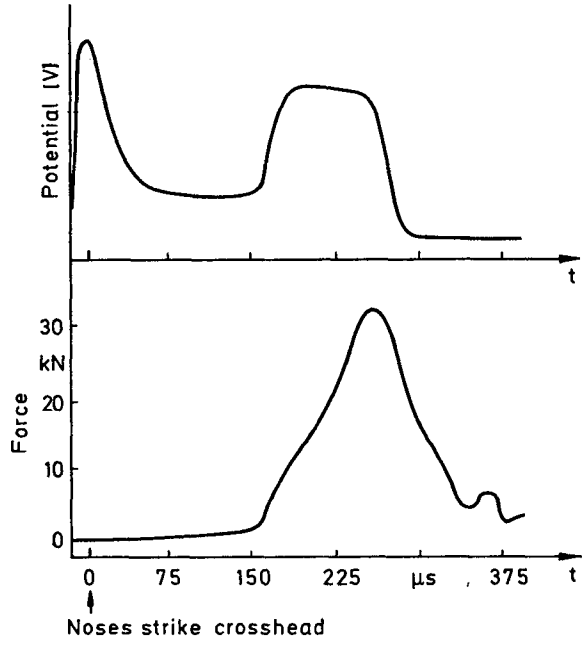


Fig. 7: Potential-vs. time and force-vs. time diagram for CT 15 specimen at 16 m/s

## 5. Conclusion

With the 33 MJ rotating disk impact machine a valuable tool is available at MPA Stuttgart to investigate the behaviour of dynamically loaded material unter various conditions (temperature, strain rate, notches, cracks etc.). Future investigations will focus on the analysis of the deformation around notched areas and crack tips.

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