CASKS FOR TRANSPORTATION AND STORAGE OF RADIOACTIVE MATERIALS AS MULTI MASS SYSTEMS - ADDITIONAL STRESSES CAUSED BY KINEMATIC EFFECTS

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Summary

If casks consist of several single components that are not attached to each other - for example inner and outer casks with a solid load, all inserted in a loose manner with significant clearance between them - special kinematic effects can take place during the drop tests. Measurements during drop test show that the contact of the inner mass with the outer mass is time-delayed relative to the contact of the outer mass with the target. As a consequence of this, it can happen that the stress will be lower than it would be if the components were attached to each other and the inertia force acted upon all masses in the same moment. On the other hand, relative movement during and after the impact - in other words, in the period of free rebound - can cause inner collisions that produce stress values which are higher than the values resulting from the initial impact itself. This paper shows some results of a drop test with a cask that is acting as a two-mass-system and the POLLUX-cask that is acting as a three-mass-system.

Introduction

Time dependent signals of strain and acceleration that you get from a drop test with a cask that is acting as a single-mass-system usually have a shape similar to a half-sine. This is the case for the period of contact with the target. For the period of free rebound, the values return to approximately zero. E.g. Figure 1 shows measured strain vs. time for a point at the outer shell surface of an empty monolithic cask. It was a puncture test with a drop height of 2 m. This height was determined such that the cask's energy in this test was the same as for a test with a complete cask (fitted with impact limiters, inner lead liner and maximum load).

If the cask consists of different components and there is some free space between the components (or the solid load), you find signals of other shapes. The reason for this is that there is relative movement between the components during the period of free drop, during the impact, and during the period of free rebound. While the cask is hanging at the crane, gravity acts on all components and causes minor deformations on the contact areas. At the moment of the drop release, this elastic deformation exerts a small pulse on both components in opposite directions. Therefore, an inner component hits the outer component with a time delay. This time delay is caused by a small difference in velocity in the first period of the drop. All subsequent relative movements result from this first different velocity and the difference in the properties of the components (elasticity, mass, clearance friction ...). These relative movements cause inner collisions with strain values that are sometimes higher than the strain values of the initial impact. This paper describes the consequences of such behavior in the cases of a MOSAIK-cask and of the POLLUX-cask.

Example for a cask that is acting as a two-mass-system (MOSAIK waste container)

For a 1 m drop test with a DCI-MOSAIK cask onto a punch bar we had to take strain measurements from the outer and the inner side of the shell near the contact point. For protection of the strain gauges of the inner side, a special liner was built and attached to the inner wall of the cask body with metal plates, leaving free space for the strain gauges in-between. To simulate the mass of the load and the mass of a lead liner usually inserted in this cask, we chose a lead bar with a mass of 4400 kg. This lead bar was inserted into the protection liner in a loose manner with a total clearance of 30 mm. Figure 2 shows the design of the test object.

The curves of the measurements taken during the test were shaped quite differently from the one shown in Figure 1 althought the cask design and energy were the same. An example for these curves is given in Figure 3. The upper graph shows strain at the inner wall vs. time, and the lower graph shows deceleration at the top of the cask vs. time. Strain shows two significant maxima that are dependent on the maxima of deceleration. We have a period of negative deceleration - in other words, acceleration in drop direction - that corresponds to the minimum of strain. The acceleration of the cask body is caused when the inertia force of the lead bar acts on the cask body with a time delay. The effects described in the introduction have caused the loose lead bar to move during the drop time relative to the cask body. At the moment of drop release, the lead bar is at the bottom line of the cask body. When the cask body hits the target, the lead bar has moved to the top line. Therefore the measured maximum strain is lower than it would have been if the lead bar had been attached closely to the cask body.

First example of a cask that acts as a three-mass-system (POLLUX spent fuel cask)

The drop tests with the POLLUX-cask showed the effects of a three-mass-system. The design of the cask is described by *Spilker et al. (1992)*, the drop tests had been described by *Gogolin et al. (1995)* and *Quercetti et al. (1995)*. A general overview of the POLLUX design is given in Figure 4. It shows the outer cask (mass $m_1 = 34$ t), the inner cask (mass $m_2 = 21$ t), and a solid steel bar simulating the load (mass $m_3 = 10$ t). Between the inner and outer casks are damping plates that are attached at the bottom and at the lid area. At the lid end of the steel bar, spacers - designed as pipes - are attached in order to simulate the possibility of deformation to which a real basket is subject. For the 9 m drop onto the unyielding target, two impact limiters (3,5 t each) were mounted. Figure 4 also gives the position of the straingauge which signal is discussed in the following text. The position of all other measuring points is given by *Gogolin et al. (1995)*.

The kinematics that occurred during and after the impact (vertical, lid down) and their effects on the strain measured at the center of the inner cask's welded lid is shown in Figure 5 and Figure 6. The deceleration curve of the inner cask starts with a time delay of 7 ms. The period of primary impact has a duration of about 20 ms and shows inverse vibration of outer and inner cask. When deceleration and strain exceed the maximum and the phase of resilience starts, there is a period of acceleration (negative deceleration) and a second increase in the strain. This effect is caused by the steel bar (simulated load) hitting the inner lid of the inner cask. The result of this internal impact is an "outer force„ acting on the inner cask. The reason for the long time delay in respect to the beginning of the impact on the outer cask is that a neutron moderator plate made of graphite and mounted to the inner lid has no significant resistance to being punctured by the distance pipes of the steel bar. This results in an effective clearance for relative movement inside the inner cask of about 75 mm.

In the middle of the period of this inner impact, there is a very short phase of decreasing strain. This is caused by spontaneous buckling of the distance pipes at the head of the steel bar. If that buckling had not occurred, it could have been assumed that the maximum of strain caused by this inner impact were higher than the maximum of the initial impact. During the entire time of the rebound of the cask, we find relative movement of the three masses. Each time the masses collide in the area of the lids, a peak in the lid strain is caused.

Second example for a cask that acts as a three-mass-system (POLLUX spent fuel cask)

Another drop test with the POLLUX-cask was executed to demonstrate the ability of the cask to withstand a 5 m drop without impact limiters onto the concrete floor of a storage building. This was executed in the position "bottom down", and no inner components were changed from the test before. Therefore, the components designed for inner damping were deformed, and the clearance between inner and outer casks, and especially between the inner cask and the steel bar, had increased. Due to this fact, we found significant peaks in the strain curve of the welded lid of the inner in the period of free rebound, see Figure 7. The maximum strain was found 90 ms after the end of the initial impact. This value was three times higher than the maximum measured during the initial impact. This extremely high peak was caused by the internal impact of the solid steel bar on the lid area of the inner cask, which threw the inner cask against the lid of the outer cask.

This example clearly demonstrates that in some cases of cask design the maximum values of stress are caused by internal impacts that happen a relatively long time after the initial impact. Impact calculations usually stop at the end of the impact and therefore, these effects are not shown. On the other hand it can be assumed that the content simulation by a solid steel bar and the plastic deformation of the impact limiting components inside the cask system in the drop tests before led to harder reactions in the case of inner impacts than the original contents (stainless steel cans filled with consolited spent fuel rods) would have done.

Conclusions

The drop test examples presented in this paper show that the interaction of loose single masses in a multi-mass-system have significant influence on the cask's stress-time relations. The presented results demonstrate the importance of a very correct simulation or assessment of the internal structure of packages. This is also very important for all FEM-calculations. These calculations has to take in account the possibility of time delayed interactions between unatached componeht's of the cask also in the time of free rebound.

References

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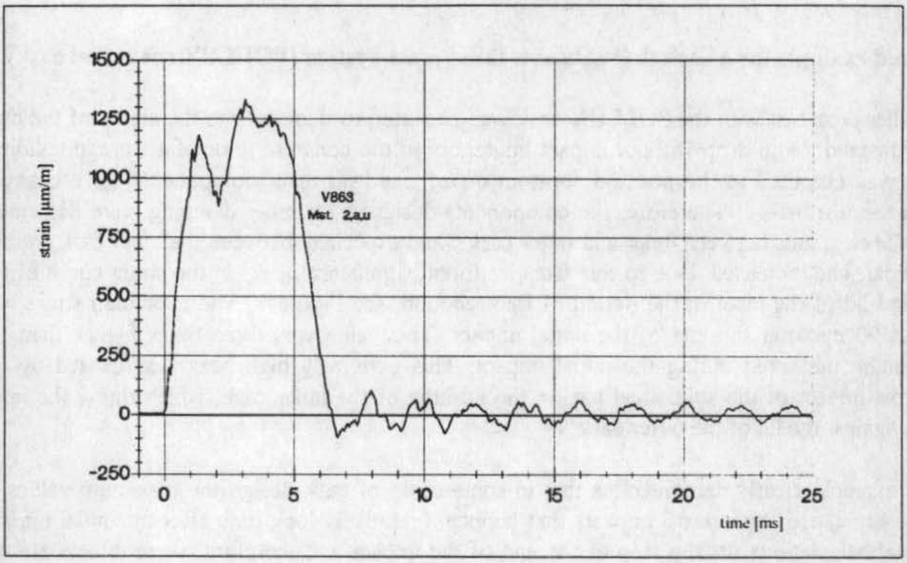

Fig. 1 Strain vs. time for a single-mass-system (MOSAIK II-15 without lead cylinder, 2 m puncture test No. 1)

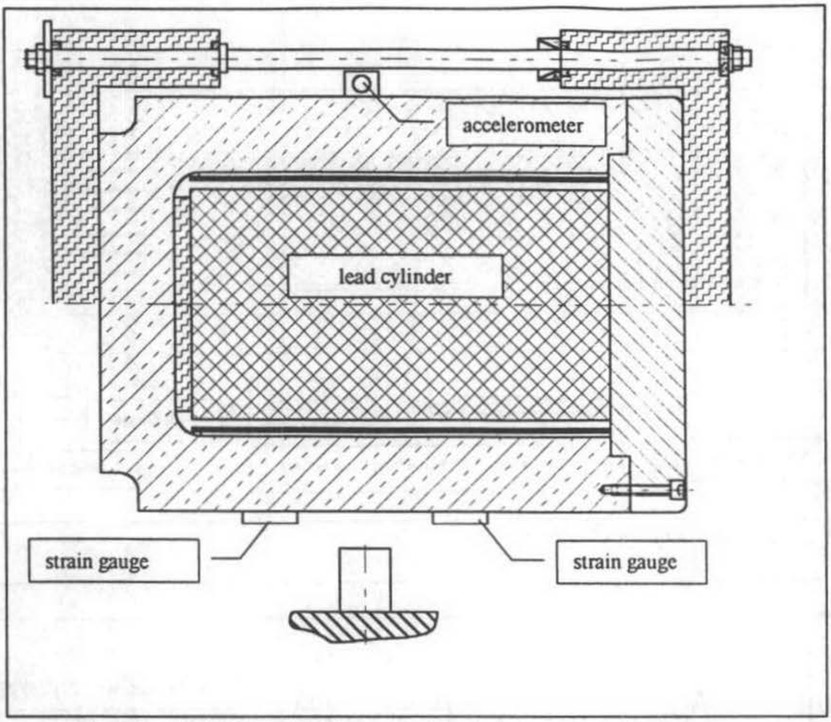

Fig. 2 Sketch of MOSAIK cask, prepared for 1 m puncture test No. 2

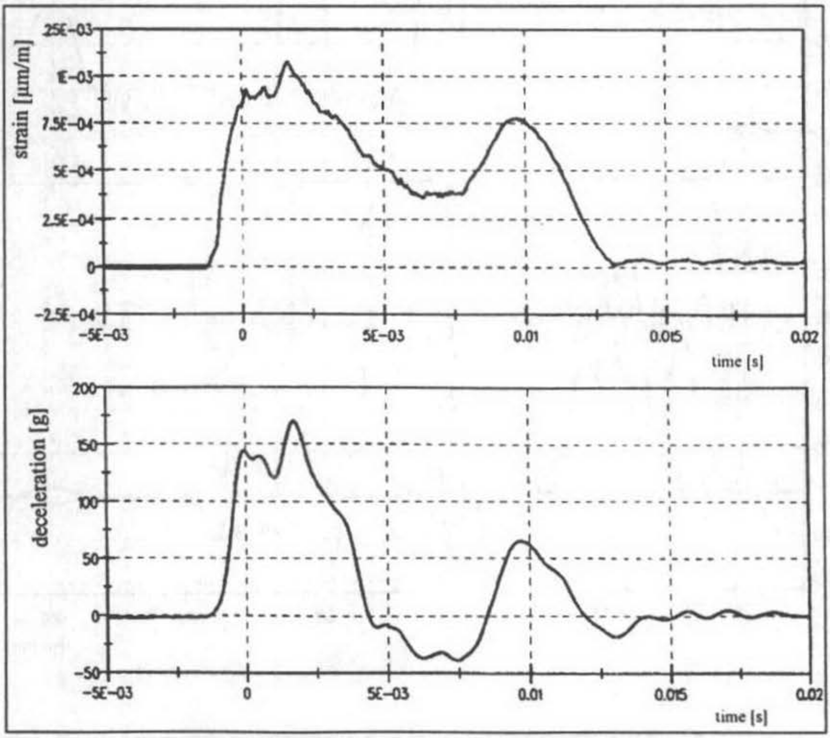

Fig. 3 Strain and decelaration vs. time for a two-mass-system (MOSAIK II-15, 1 m pucture test No.2)

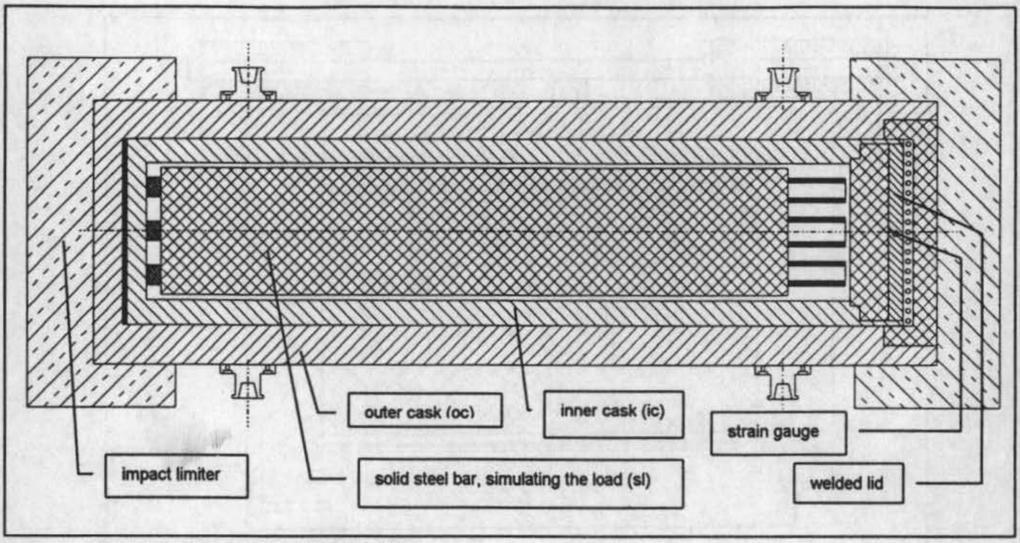

Fig. 4 Key plan of the POLLUX Cask

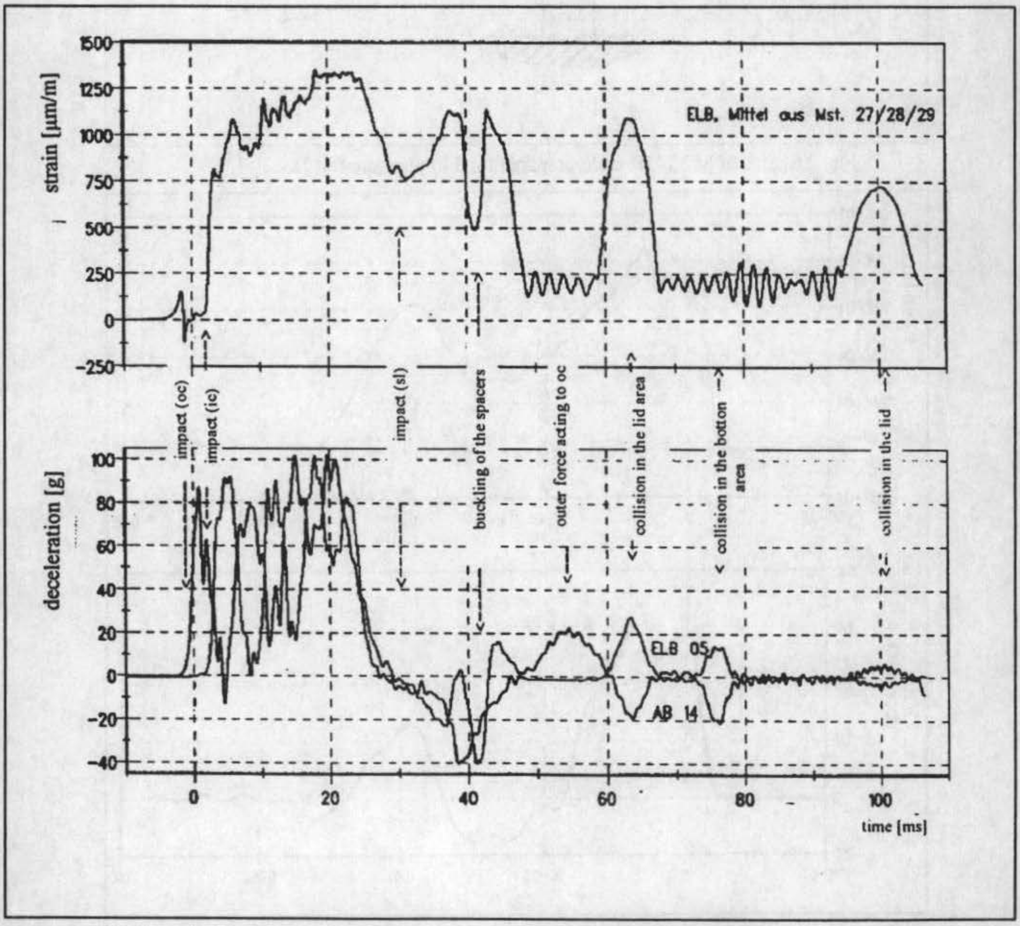

Fig. 5 Strain and decelaration vs. time for a three-mass-system (POLLUX cask, 9 m vertical drop, lid down)

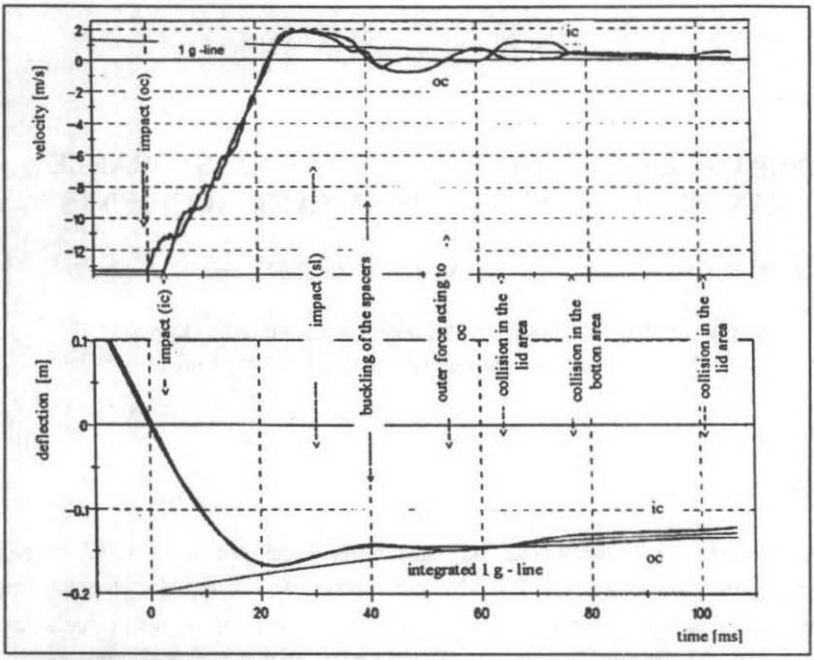

Fig. 6 velocity and deflection vs. time for a three-mass-system (POLLUX cask, 9 m vertical drop, lid down)

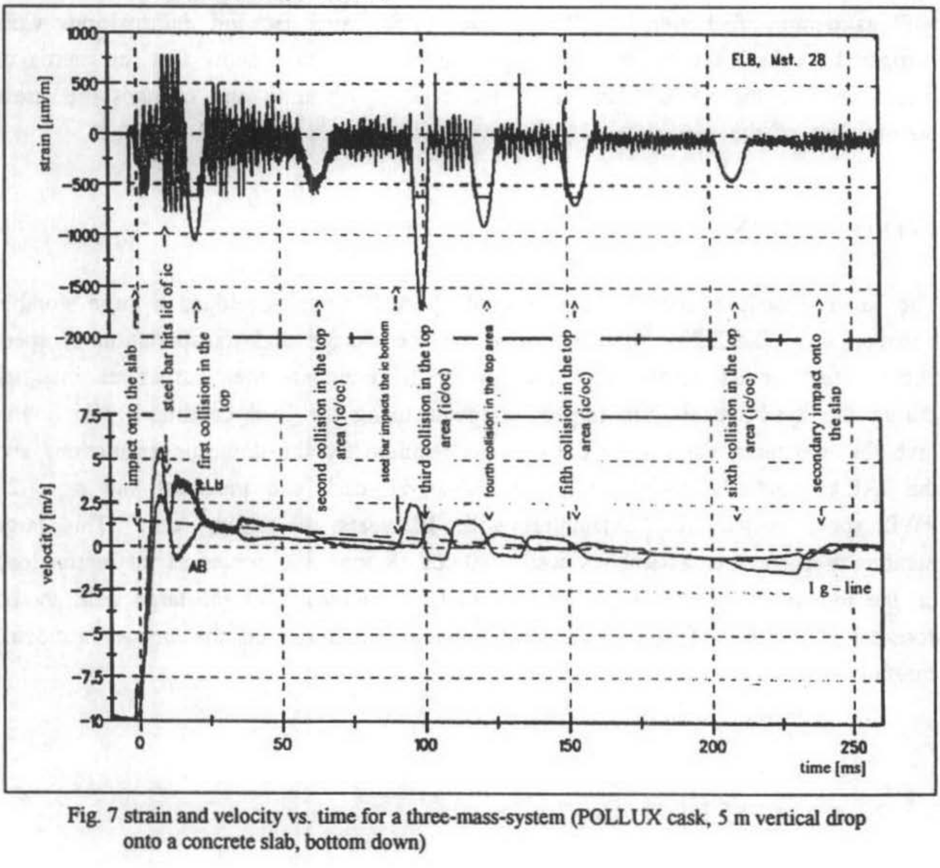

Fig. 7 strain and velocity vs. time for a three-mass-system (POLLUX cask, 5 m vertical drop onto a concrete slab, bottom down)