Box 11: Earthquake Protection of the Bucharest FN Tandem Accelerator

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The HVEC FN tandem accelerator, commissioned in Bucharest in March 1973, is operated at a terminal voltage of up to 8.5 MV and delivers a wide range of ion species from protons to gold ions, used for atomic- and nuclear-physics research as well as for applications (AMS, PIXE, ERDA and RBS analysis). The operation of the Bucharest tandem accelerator was interrupted for long periods of time owing to the disastrous damage caused to the column structure in the tank [1, 2] by major earthquakes in 1977 (magnitude 7.2 on the Richter scale) and 1986 (magnitude 6.9). After the second event and the subsequent second very expensive repair of the tandem column, a concept for earthquake protection of the accelerator was developed.

The concept of an earthquake protection system was based on a study aimed at providing a better understanding of earthquake effects upon the column structure as a result of the dynamic interaction between the seismic ground motion, the building, the accelerator tank and the column. In order to experimentally characterize the dynamic properties of this complex system, its response to the microseismic movements of the ground and to oscillations induced by 20 m deep underground TNT explosions close (150–215 m) to the building were recorded. The most critical component of the horizontal tandem accelerator is the column, since it presents a capability to resist accelerations of only $0.1g$ for transverse horizontal forces, while the peak acceleration during the 1977 earthquake was $0.4g$ ($g = 9.81\,\mathrm{m/s^2}$). More than that, the column has a natural mechanical frequency of 2.1 Hz in the horizontal direction, coinciding with the dominant frequency at the maximum acceleration specific to the earthquakes produced in the Vrancea region of Romania, as well as with the eigenfrequency of the rocking motion of the building. The origin of the column damage resided therefore in the coincidence between the natural frequencies of the column, the building and the ground motion during the earthquakes, resulting in a mechanical resonance centered around 2 Hz. Several technical solutions for an earthquake protection system for the Bucharest tandem accelerator were taken into consideration:

– improvement of the radial stiffness of the column with a portico system, such as that used in the Vivitron tandem accelerator, or with four rods automatically pushed into the tank in order to rigidly support the terminal;

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– isolation of the tank from ground oscillations by a pendulum-type system or by efficient oscillation damping through a soft elastic suspension with springs and viscodampers.

The last solution, implying support of the accelerator tank (14 m long, 3.6 m diameter and 60 t weight) on spring and damper units, was preferred, being considered technically and economically the most adequate for the Bucharest tandem accelerator. The four accelerator tank legs have each been equipped with special elastic units, designed and made by GERB GmbH, Essen, Germany. Each unit consists of four soft springs and one viscous damper. When the accelerator tank is freely swinging on these elastic suspensions, its natural frequencies are lowered to 0.5 Hz in the horizontal direction and 0.9 Hz in the vertical direction. Except in the vicinity of the resonance, the force transmitted by an undamped isolator is practically proportional to the square of the ratio between its natural frequency and the excitation frequency. Therefore the elastic supports reduce the horizontal force induced by an earthquake in the column by a factor of over 10, sufficient to provide efficient column protection for earthquakes as strong as the one in 1977. The maximum allowed displacements of the tank are ± 180 mm horizontally and ± 50 mm vertically.

A special problem arises from the fact that the soft springs do not ensure the stability of the tank position required by the accelerator tubes and the alignment of the stripper with the general ion-optical axis of the tandem. In order to solve this problem, special devices, which might be called "mechanical fuses", have been designed [3] and installed. Each tank leg is provided with four mechanical fuses, and there are two more at the two ends of the tank. The mechanical fuses continuously lock the tank in the desired position, dictated by the alignment requirements, and release the tank on to the elastic modules at the beginning of an earthquake, but only if the horizontal acceleration of the floor exceeds a preset value. The mechanical fuses also allow vertical adjustment of the tank position. The general layout of the system in Fig. B11.1, and a view of a spring and damper unit equipped with mechanical fuses is shown in Fig. B11.2.

The simultaneous release of all mechanical fuses is automatically performed by a specially designed triggering system consisting of an earthquake sensor and a nitrogen-pressurized network of tubes connected to the mechanical fuses. The mechanical fuses are locked as long as the pressure in the gas network is in the range $(8-10) \times 10^5$ Pa. If the pressure drops below a preset value, the mechanical fuses are unlocked and the accelerator tank is released on to the springs.

The earthquake sensor, which is completely free from conventional sources of energy that may fail during an earthquake, consists of a 76 mm diameter steel ball seated in an unstable balance at the top of a 3 m long vertical tube. When the ground acceleration exceeds $0.05g$, the ball falls down and activates a release system consisting of switches and a pressurized glass tube placed at

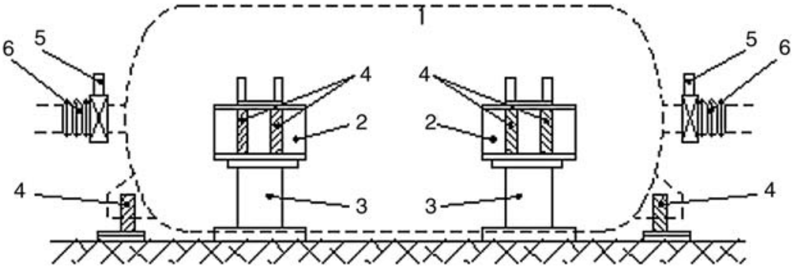

Fig. B11.1. General layout of the earthquake protection system: 1, tank; 2, spring and viscodamper units; 3, tank legs; 4, mechanical fuses; 5, protection gate valves; 6, fragile aluminum tubes

Fig. B11.2. View of an elastic unit with springs, damper and mechanical fuses

the bottom of the vertical tube. The switches, activated by the falling ball, switch off the accelerator belt motor and close the gate valves installed on both ends of the accelerator tubes in order to prevent damage to the tubes caused by breaking of the vacuum (these actions occur at $t = 0.5 - 1\,\mathrm{s}$ after the moment $t = 0$ when the ball starts to fall). After that, the falling ball breaks the glass tube, the pressure drops, unlocking the mechanical fuses, and the tank is completely released on to the springs, slow vertical damped oscillations of the tank starting at $t = 2.5\,\mathrm{s}$. In order to protect the LE and HE beam components, fragile short aluminum tubes were inserted at both ends of the tank, between the beam components and the accelerator tubes. When the tank is released on to the springs, these two tubes are broken after the closing of the gate valves.

The system has been tested several times by forced excitation of the earthquake sensor and, so far, only once in real conditions (May 1990, earthquake of magnitude 6.4), when the system behaved properly [4, 5].

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