The aim of the project consists in investigating the mechanisms of adaptation and inadaptation of structures made of modern materials (multiphase and composite), subjected to cyclically variable loads at extremely low temperatures (liquid nitrogen, 77K, liquid helium, 4.2K, and superfluid helium, 1.9K). Adaptation to cyclic loads (the so-called shakedown) is of key importance for the lifetime of the object (structure), expressed in the number of cycles to failure. The phenomenon of adaptation (shakedown) is measured by means of energy dissipated on single load cycle. If the energy dissipated decreases from cycle to cycle, and eventually reaches zero, the elastic shakedown takes place. Otherwise, when the phenomenon of inadaptation to cyclically variable loads occurs, the energy dissipated on subsequent cycles increases, which leads to degradation of physical and mechanical properties of the material and to accelerated failure. One of the phenomena related to inadaptation to cyclic loads is the so-called ratchetting, the main feature of which consists in constant increase of the average strain (or stress) on each subsequent load cycle. The above phenomena were thoroughly investigated in the context of room or elevated temperatures, while in the world literature there are practically no studies of these phenomena at cryogenic temperatures, including the proximity of absolute zero.
The main goal of the project consists therefore in determining whether the phenomena of adaptation and inadaptation to cyclically variable loads occur at extremely low temperatures, and whether the adaptation to cyclic loads is accelerated, as might be deduced from much higher yield stress of metals and alloys when compared to room temperature, as well as from the phenomenon of plastic strain induced phase transformation from the austenitic (plastic) to the martensitic (elastic) microstructure occurring in metastable materials. Due to these factors, the adaptation process at cryogenic temperatures can probably take place faster than at elevated temperatures. If, on the other hand, the phenomenon of inadaptation (ratchetting) takes place, it might be useful to ask what its nature is, what mechanism causes the failure at extremely low temperatures and whether the number of cycles to failure is subject to similar laws as at elevated temperatures. In particular, it should be asked whether the phenomenon of intermittent (discontinuous) plastic flow, characteristic of temperatures close to absolute zero, affects the ratchetting phenomenon and may accelerate the process of material degradation as well as the failure of structure subjected to cyclically variable loads.
The proposed research includes multiple experiments conducted at extremely low temperatures (77K, 4.2K, 1.9K) under the multiaxial cyclic loads, involving tension or compression and torsion. The tests will be carried out by using unique set-up consisting of vacuum insulated cryostat, special device used to implement cyclic multiaxial loads, including proportional and non-proportional loading paths. The test set-up will be modified in order to enable implementation of the cyclic loads in both directions: axial and angular. The set-up will be equipped with the acoustic sensors to identify the mechanisms of material degradation, as well as the feritscope to analyze the degree of phase transformation (volume fraction of secondary phase). The evolution of the microstructure during cyclic loading will be examined by using Scanning Electron Microscope, equipped with EBSD (crystallography) and EDS (chemical composition) detectors, and by means of the synchrotron radiation. Moreover, a physically justified, multiscale constitutive model of metastable materials, taking into account intermittent (discontinuous) plastic flow, will be used and extended to cyclic loads.
The problem raised in the project is key to the design and optimization of complex superconductivity-based systems operating at extremely low temperatures, both on the ground and in the space. Most of such devices operate under the cyclically variable loads, including temperature and pressure oscillations as well as cyclic changes of surface or mass loads. The construction of superconducting particle accelerators (such as the Large Hadron Collider, LHC, or the Future Circular Collider, FCC), the instruments for research by means of magnetic resonance, such as the NMR magnets for medical applications, or the magnets of the International Fusion Reactor, ITER, requires thorough analysis of structures from the point of view of adaptation/ inadaptation to cyclically variable loads. The literature review clearly shows, that the number of publications on this topic is very small, the problem posed is completely original, and the project is fundamental and novel.