§4. Stress/Strain and their Hysteretic Effects on the Critical Current of Superconducting Wire

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1. Introduction

Due to its high Bc_2, Nb_3Sn superconducting wires are widely used for high field superconducting magnets. However the critical current, I_c, of them is known to be very sensitive to the applied stress/strain. Therefore the effect of stress/strain on I_c has to be evaluated. Allowable space for the experiment where high magnet field is generated is in a bore within about 50mm diameter. Since a magnetic field perpendicular to a wire axis is more sensitive to I_c than the other directions, loading direction has to be converted from vertical to horizontal by a rotating lever or so on. Tensile experimental Rods as shown in Fig.1 are apparatuses with which the above required experiment in a narrow space can be conducted.

2. Tensile Experimental Rods

A displacement of a wire had been measured by a lever type clip gage with its sensitivity of about 1,000με/mm. It measures relative displacement from the light hand body to the rotating lever (Fig.1(a); naming Rod 1). Ideal direct measurement by Nyilas type clip gage could not be conducted because a back plate for a support of electromagnetic force to a wire interfered with the gage position. Therefore new designed back plate and another Nyilas type clip gage with gage length 13mm and its sensitivity of about 2,000με/mm were made (naming Rod 2).

3. Result of Cu dummy wire

As shown in Fig.2, nominal extra displacement and resultant much overestimated strain - difference between strain by Rod 1 and reference one by axial tensile test - were detected at RT. The same slope of stress/strain curve with a linear portion of reference axial tensile test was obtained only at a beginning of unloading curve encircled by dot line in Fig.2. Since sensitivity of a strain gage is possible to be changed in high magnetic field and low temperature, reliable measurement by a single gage is difficult. 2 or 4 strain gages bridging sensors like a clip gage and accurate calibration to a referent displacement in the field are needed. From the comparison of measured strains at RT between the test by Rod 1 and an axial tensile test, overestimated strain of Rod 1 was found to be caused by elastic-plastic deformation of a Sn-Pb solder. The solder is used for not only a current terminal but also mechanical loading attachment. Since the proof stress of the solder increases with cooling to 77K, the difference at 77K became much smaller than that at RT. The difference has not come into the open yet, because an experiment of stress/strain effect on I_c has been conducted at LHe. However elastic-plastic deformation of Sn-Pb solder at LHe has to be measured for an improvement of the precision of strain data by Rod 1. On the other hand, since wire displacement of Rod 2 is the result of direct measurement by Nyilas type clip gage, almost the same stress/strain curve with reference axial tensile test can be obtained by Rod 2. However movable range of Nyilas type clip gage is limited because of peculiar shape of the new designed support plate of an electromagnetic force.

Axial load P is provided by stepping motor located on the Rod. A displacement of the end point of the rotating lever being 1μm corresponds to about 15 pulse of stepping motor. A linearity of the displacement versus pulse under no rotating constraint on lever – without a specimen – was confirmed. Therefore the calibration of Nyilas type clip gage in a high magnetic field and LHe can be conducted by this pulse control stepping motor system.

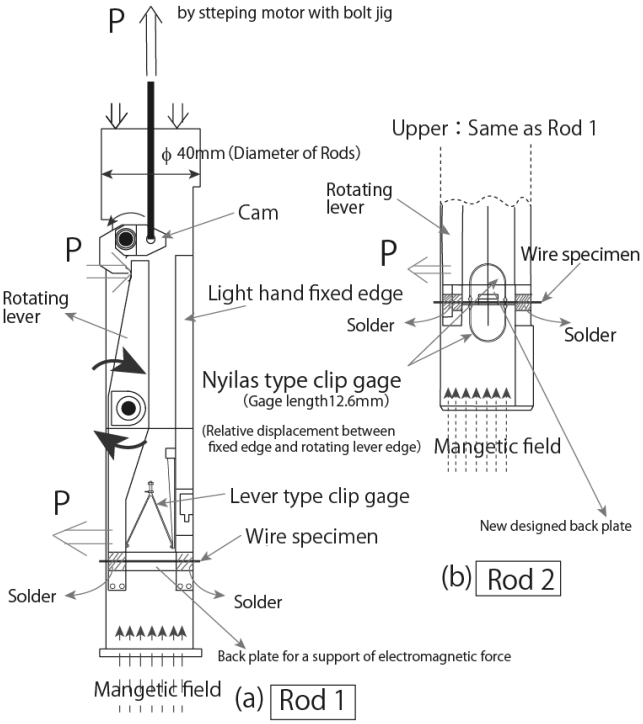

Fig.1 Mechanism of experimental apparatuses Rod 1 and 2

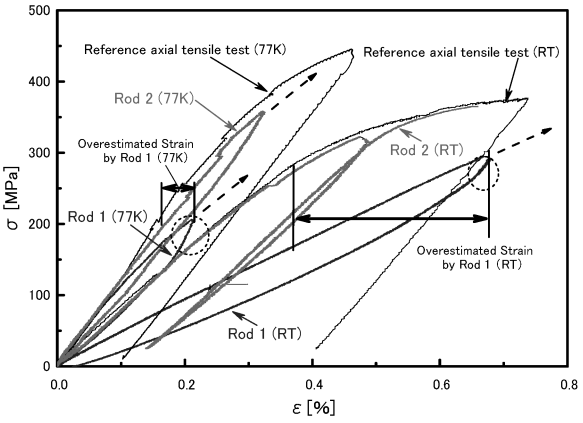

Fig.2 Measured stress-strain curves of Cu dummy wire