Investigation of Characteristics of No-Insulation Coil Considering the Influence of Stress Distribution on the Turn-to-Turn Contact Resistivity

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Abstract—The No-Insulation (NI) winding technique is a utility approach to realize high field magnet. As operation current can pass through adjacent turns, turn-to-turn contact resistance becomes one of the decisive factors that influence the thermal stability and excitation delay behavior of NI magnet. The turn-to-turn contact resistivity is mainly affected by the material of tape and turn-to-turn contact stress. Since the stress distribution in most design examples are scarcely considered, a mean resistivity is obtained through experimental test. In order to design the contact resistivity and ensure the NI magnet achieve the engineering standards, this paper investigates the pre-tightening force, thermal stress and electromagnetic force in the process of manufacturing, cooling and excitation of the high temperature superconducting NI magnet. A distribution of the contact resistivity is obtained considering the varying tendency of the contact resistivity while stress changing. Equivalent circuit model and finite element model are applied to analyze the excitation characteristics of the NI coil. The results are compared with the mean resistivity value model and can provide theoretical basis for the design of the NI magnet..

## I. Measurement of contact resistance dependence of pressure.

The contact resistance of different number of tape stacks is measured: R1, R2 and R3 are the total resistance when the number of layers are 2, 3 and 4. The contact resistance is obtained by subtracting each Ri and take the average value as the resistance value of the turn to turn contact, the contact resistance dependence of pressure is shown below.
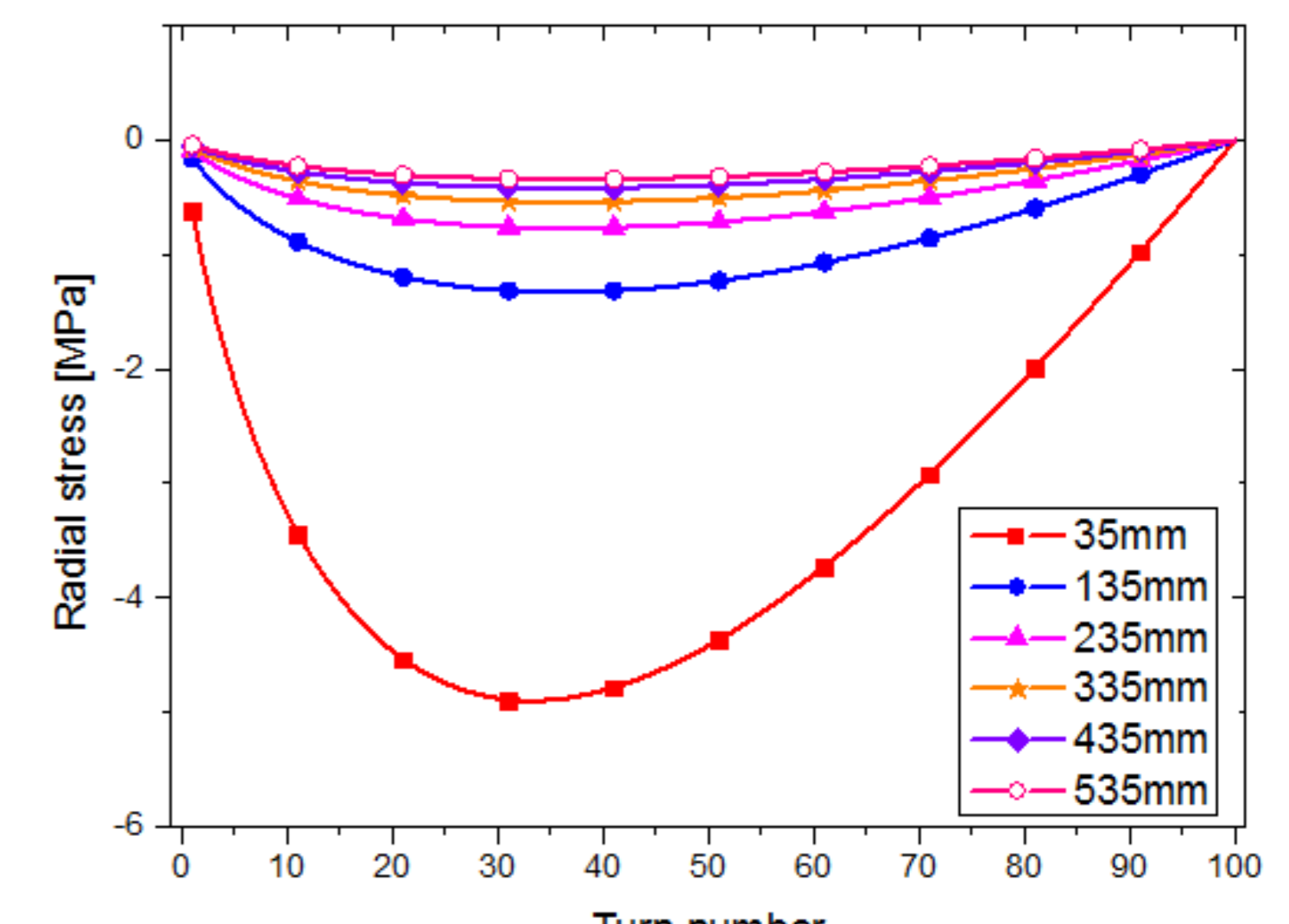

	Total resistance	Number of layer	Consist of the resistance
1	R_1	2	Rc
2	R_2	3	2Rc
3	R_3	4	3Rc
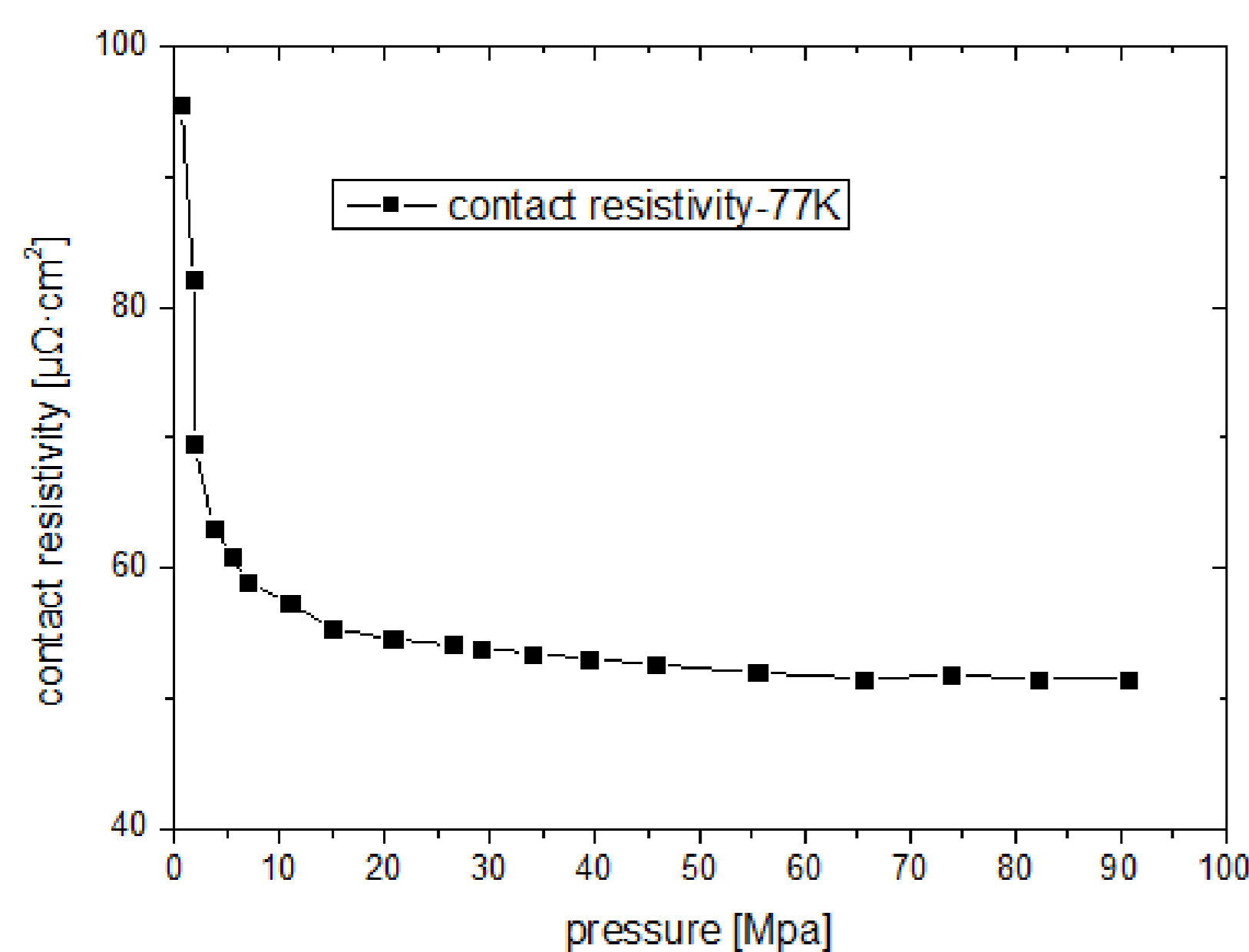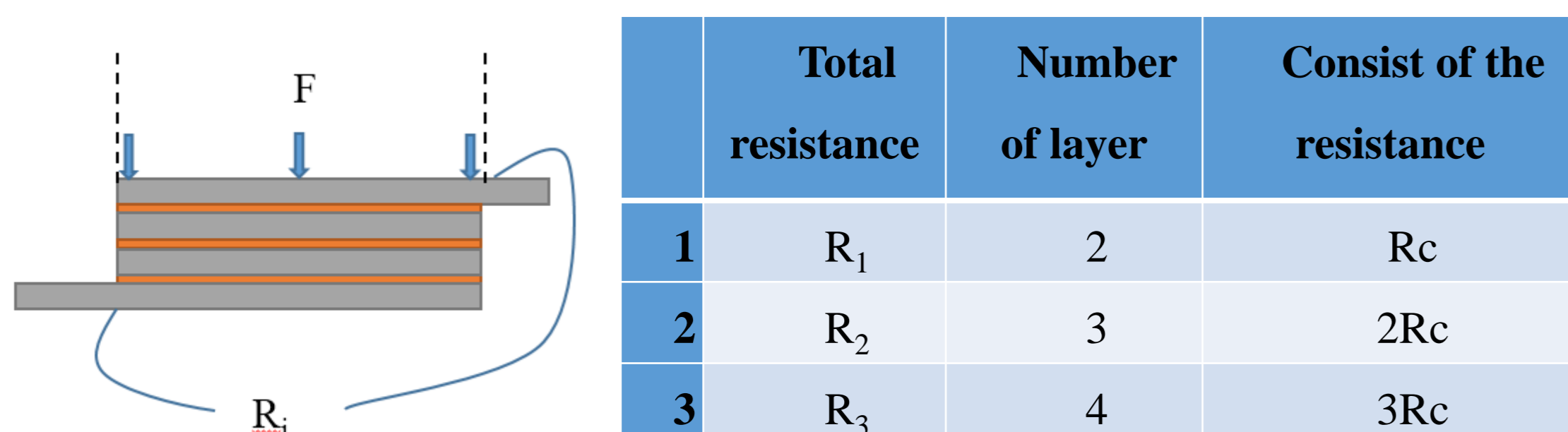
II. Stress analysis of single no-insulation coil.
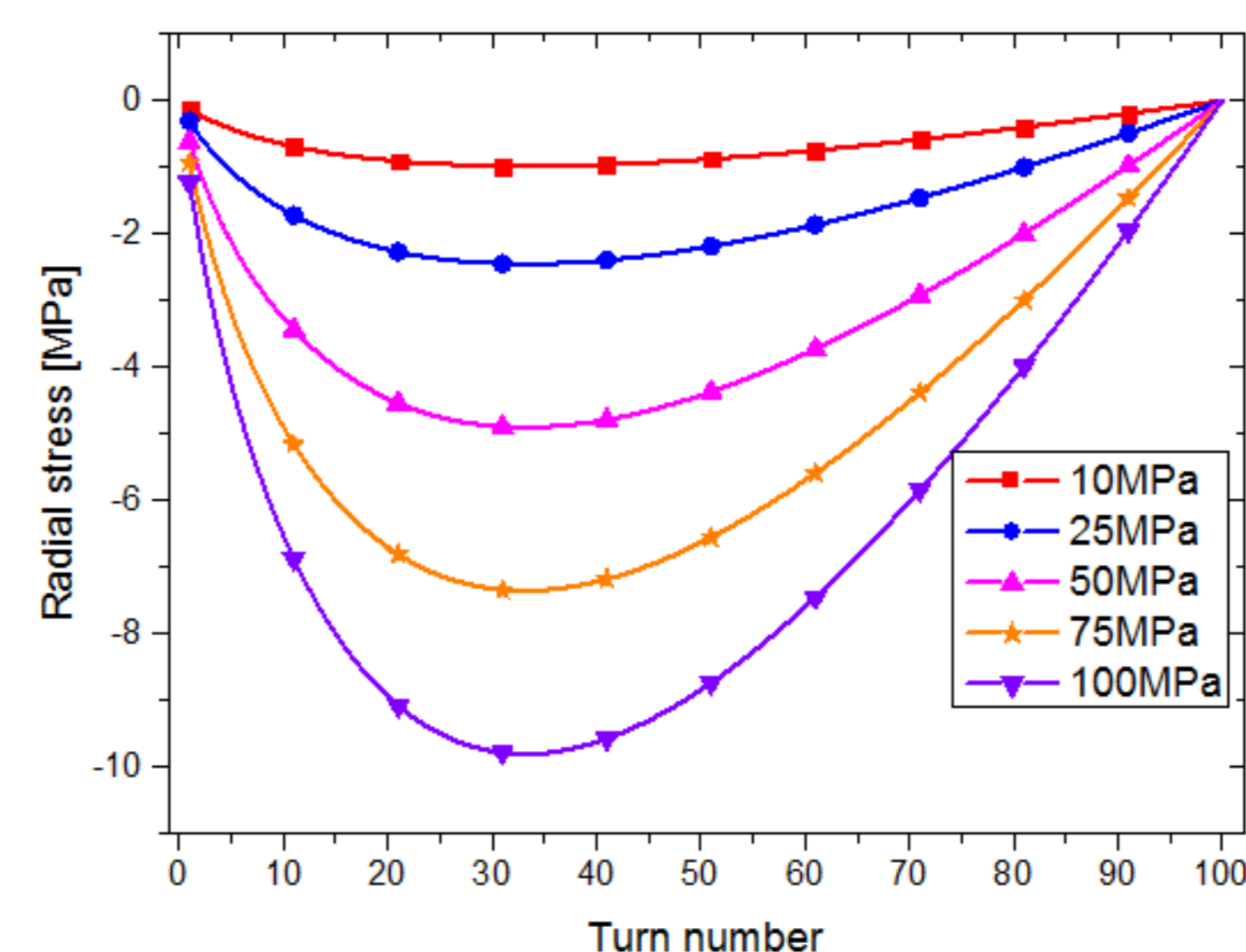
(a) Prestress varies with winding stress

(b) Prestress varies with inner radius
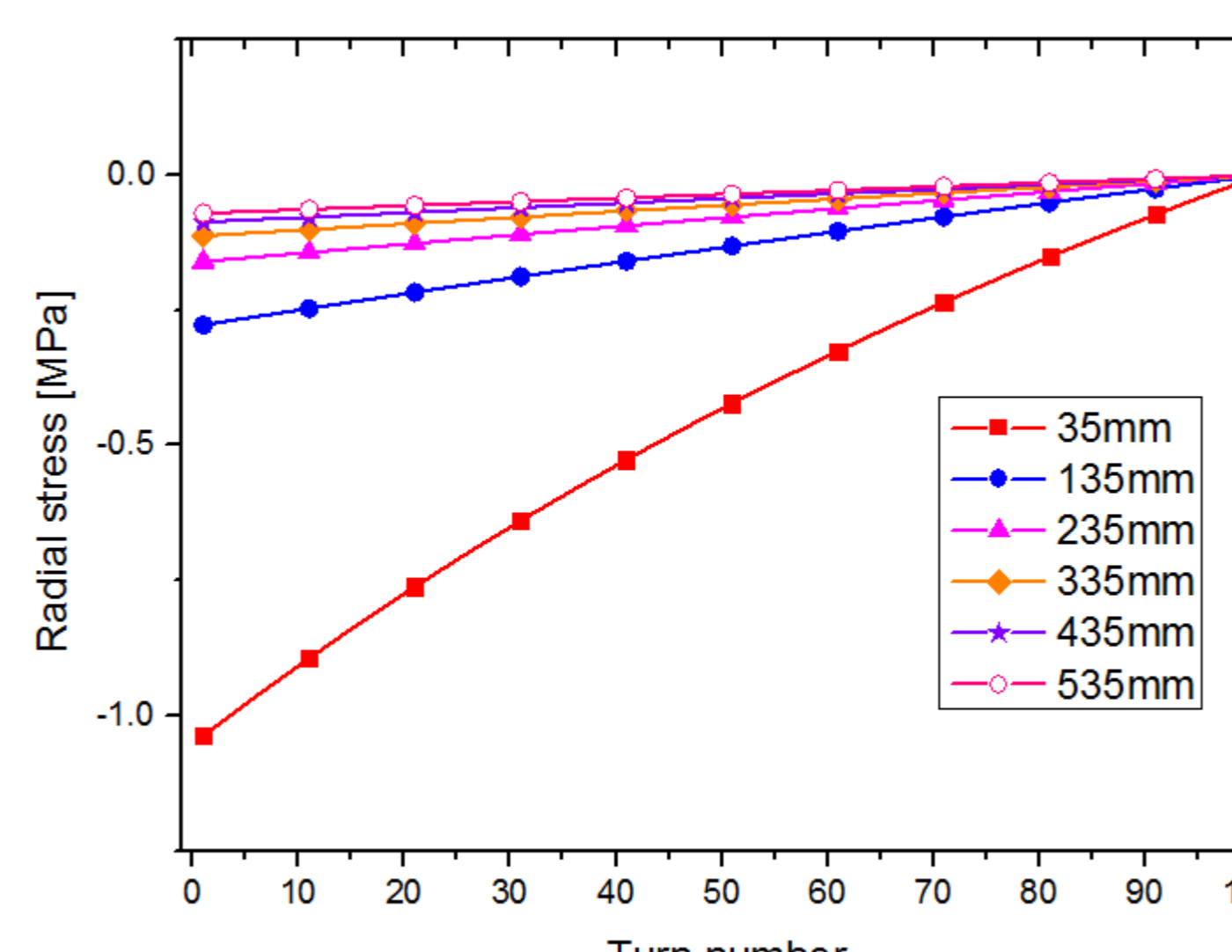
(c) Thermal stress varies with prestress (293K-77K)
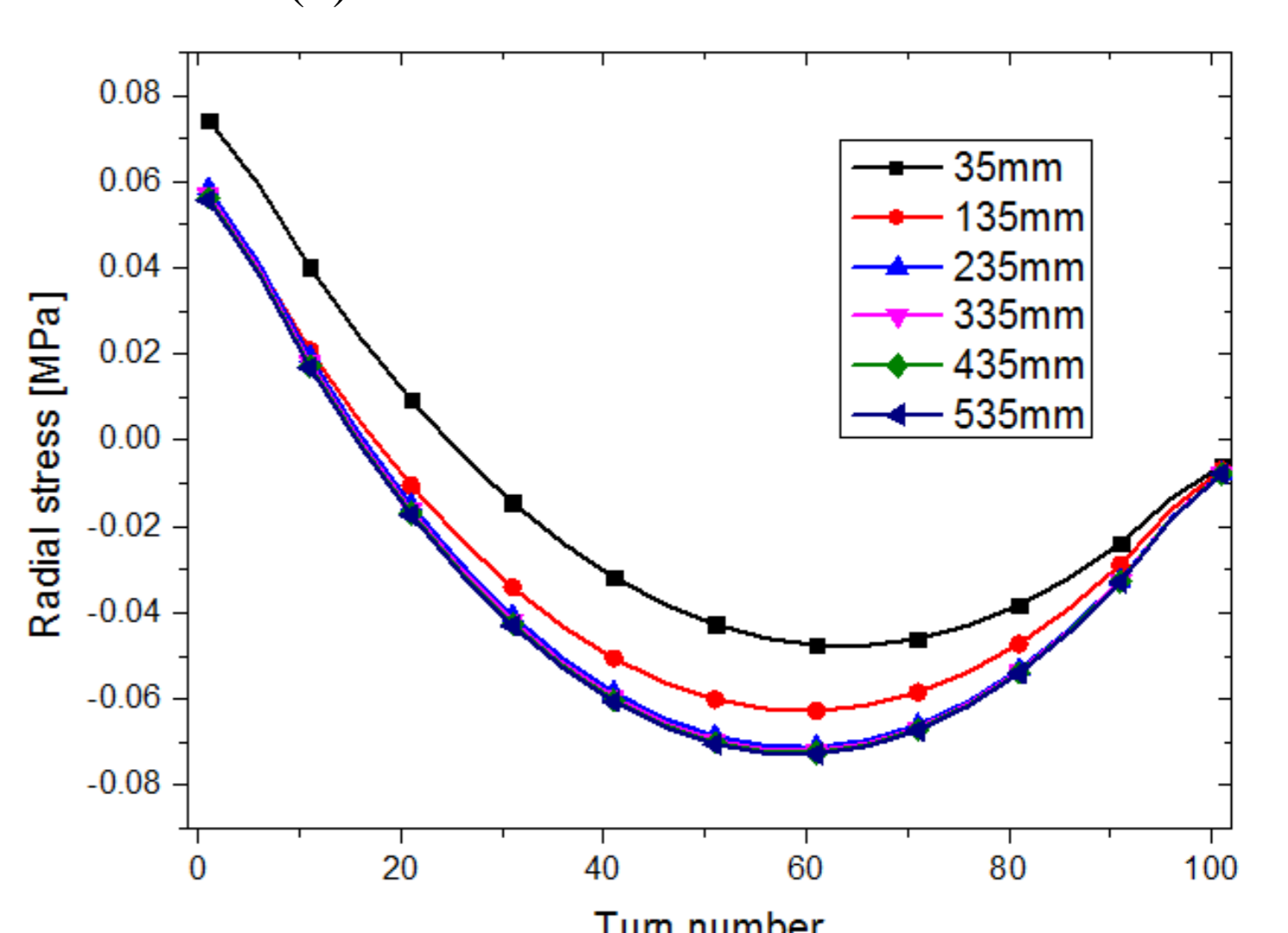
(d) Electromagnetic stress varies with inner radius

The frame is made of 316L stainless steel, the superconducting tape is SCS4050 narrowband, with 4mm width and 0.1mm thick. The radial stress due to the prestress, cooling down and electromagnetic force are calculated varies with the inner radius of the coil. The prestress is calculated by the equivalent thin-walled barrel stacking method. The thermal stress is mainly caused by the expansion of materials and can be expressed by linear expansion coefficient.

III. Contact resistance distribution under different prestress

### A. Radial stress by constant winding stress of 50MPa and 5MPa
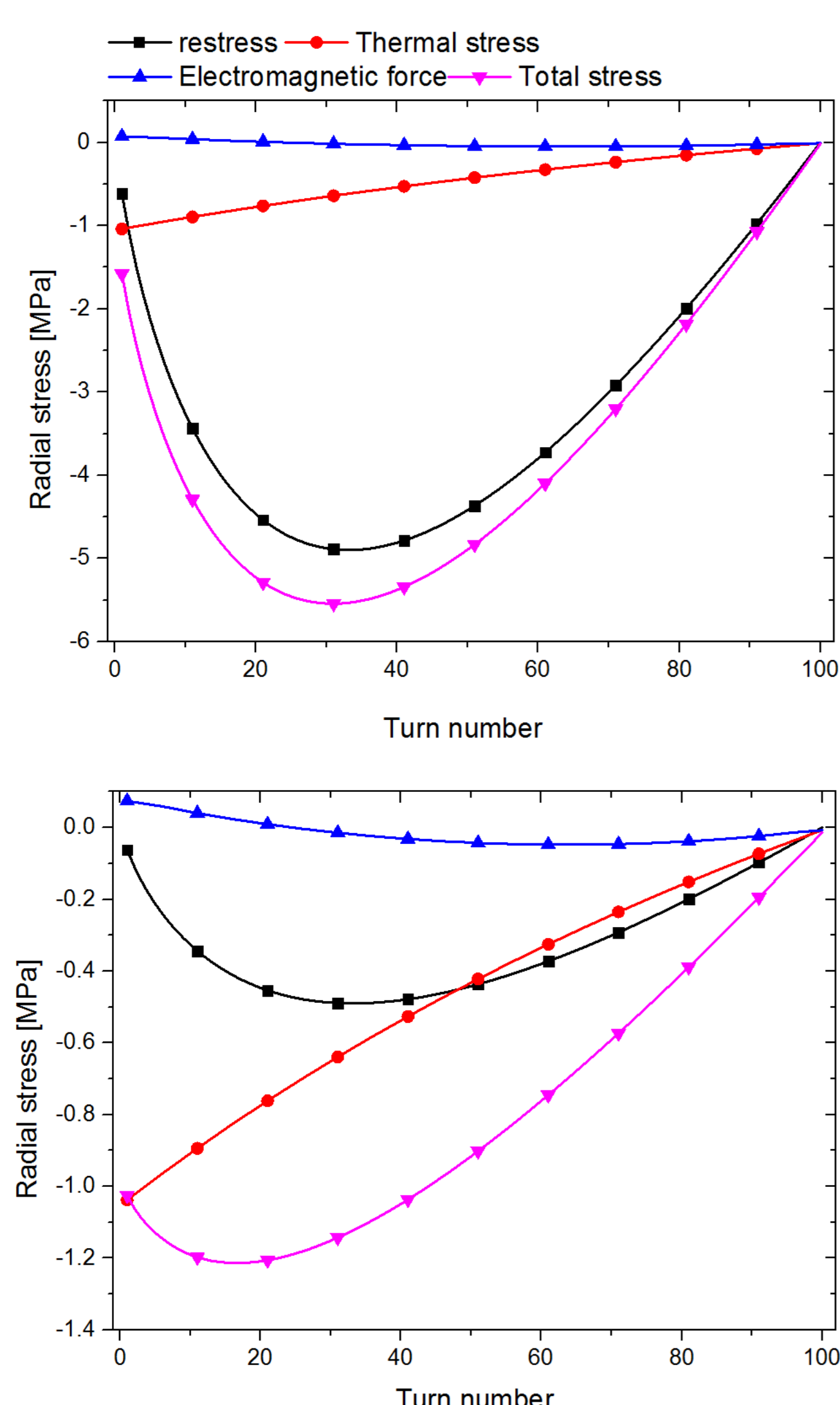
A certain amount of prestress is required to ensure the mechanical stability of the coil. Here we compare the total radial stress distribution of the coil under larger and smaller winding stress. The inner radius of the coil is 35mm and the critical current is 59A@77K. In the case of 77K, the current density is low, thus the electromagnetic force is so small that the radial stress is mainly composed of thermal stress and prestress.

B. Radial stress by winding stress F(1) and F(2)
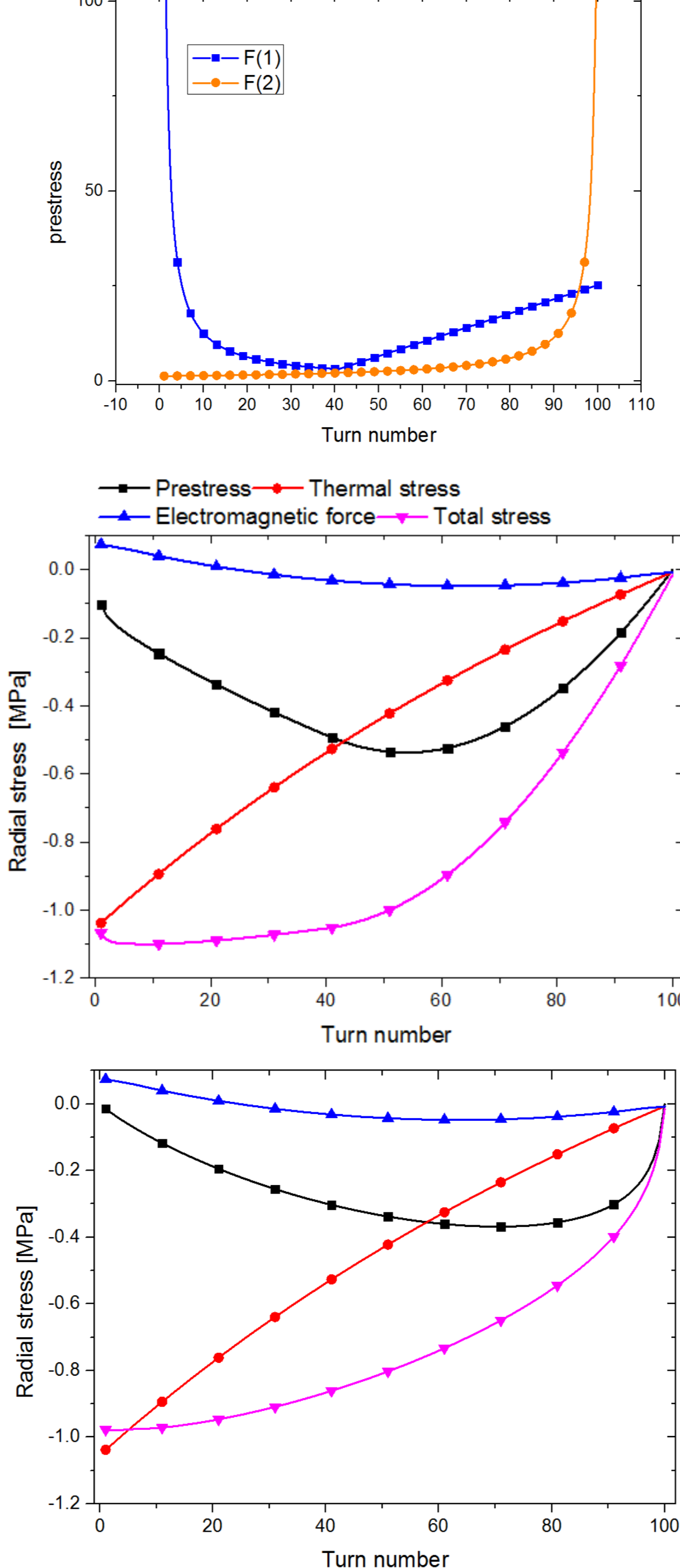

C. Contact resistivity and contact resistance
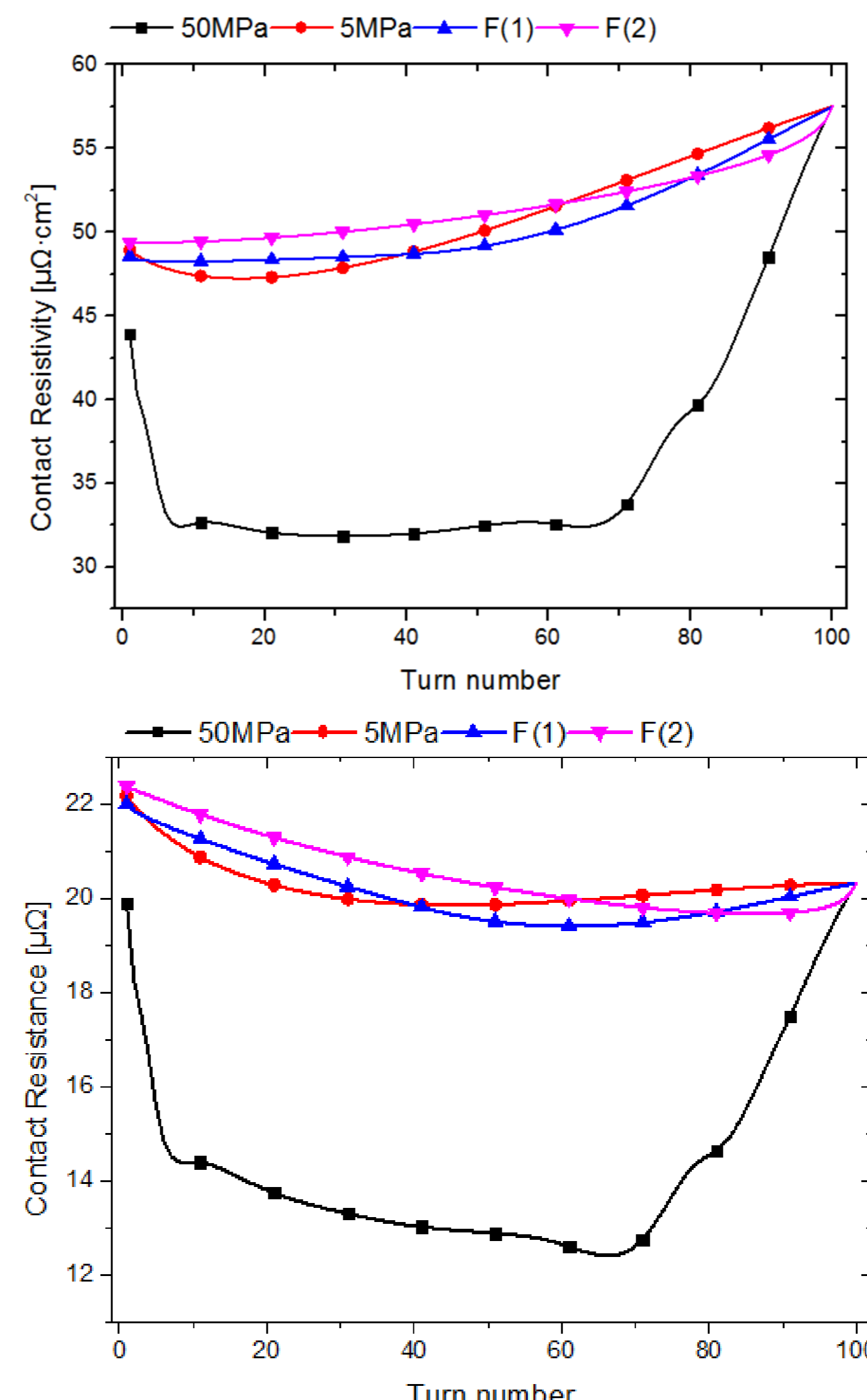
Reducing the winding prestress can effectively reduce the radial stress, the inter turn contact resistance and the inter turn contact resistance are obviously increased, which lead to a reduce of excitation time and loss. F(1) and F(2) are used to verify the effect of non-uniform winding prestress on change of resistance between turns. The average contact resistivity of F-5MPa, F(1) and F(2) are 50.73, 50.43 and 51.4 μΩ·cm2.

D. Energy loss analysis of the DC SFCL prototyp
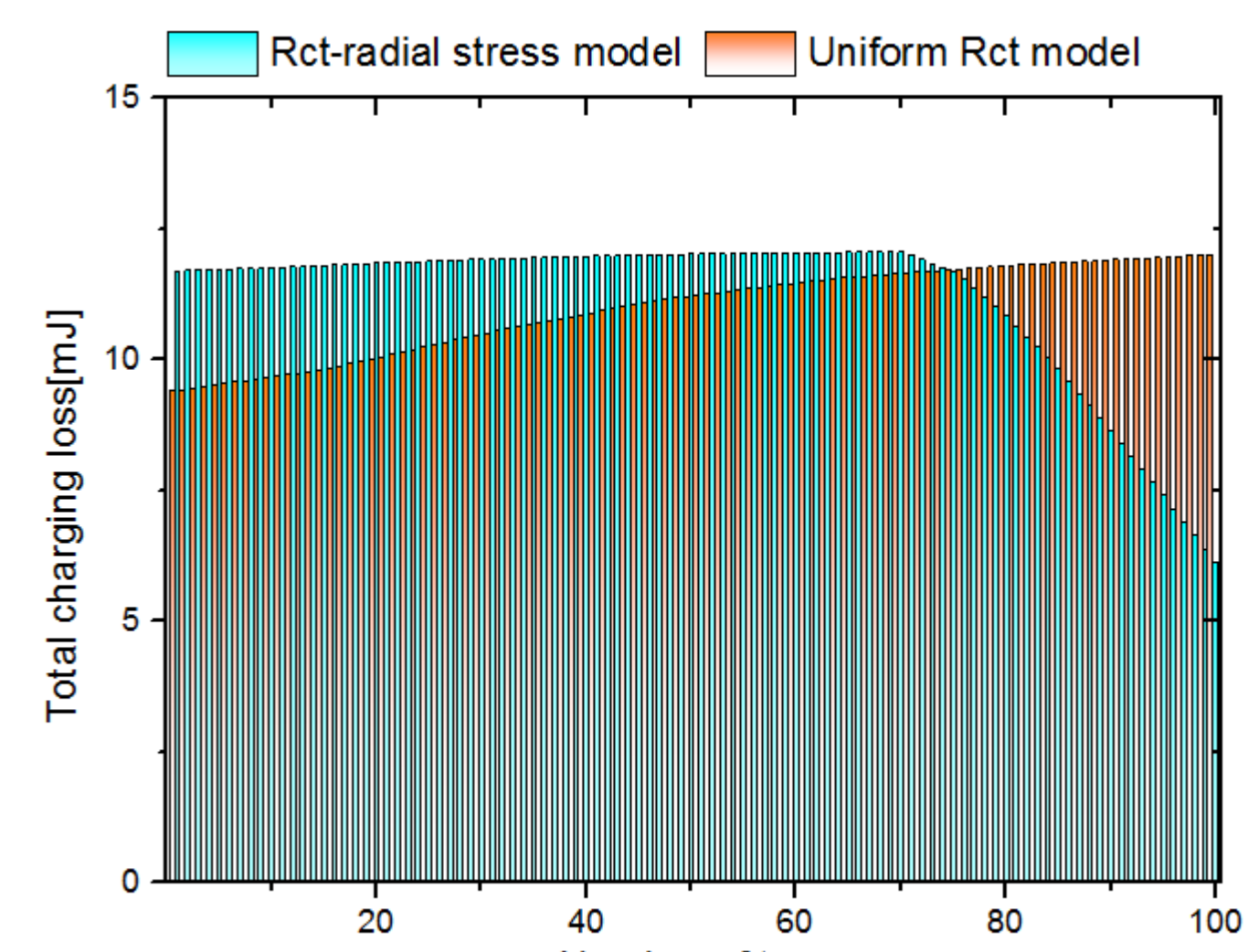
The distribution of the total chargin loss in each turn is given by the two models, employ F(2) and 51.4 μΩ·cm2. Total coil loss of the two models are both 1.11J, but the distribution of the losses in the coil is obviously different.

IV. CONCLUSION

This paper based on the analysis of stress distribution, loss distribution in the process of self excitation was calculated, and the calculation results are compared with uniform Rct model. The total loss is equal while the distribution are quite different. The establishment of the calculation model for the accurate analysis loss of NI coil. However, the effect of changing stress distribution to reduce the characteristics of the NI coil at 77K is not obvious, the method may be more applicable when the electromagnetic stress is greater and the temperature is lower, which remain to be further discussed.