A device for characterizing the circumferential strain dependence of the critical current in MgB_2 wires and tapes

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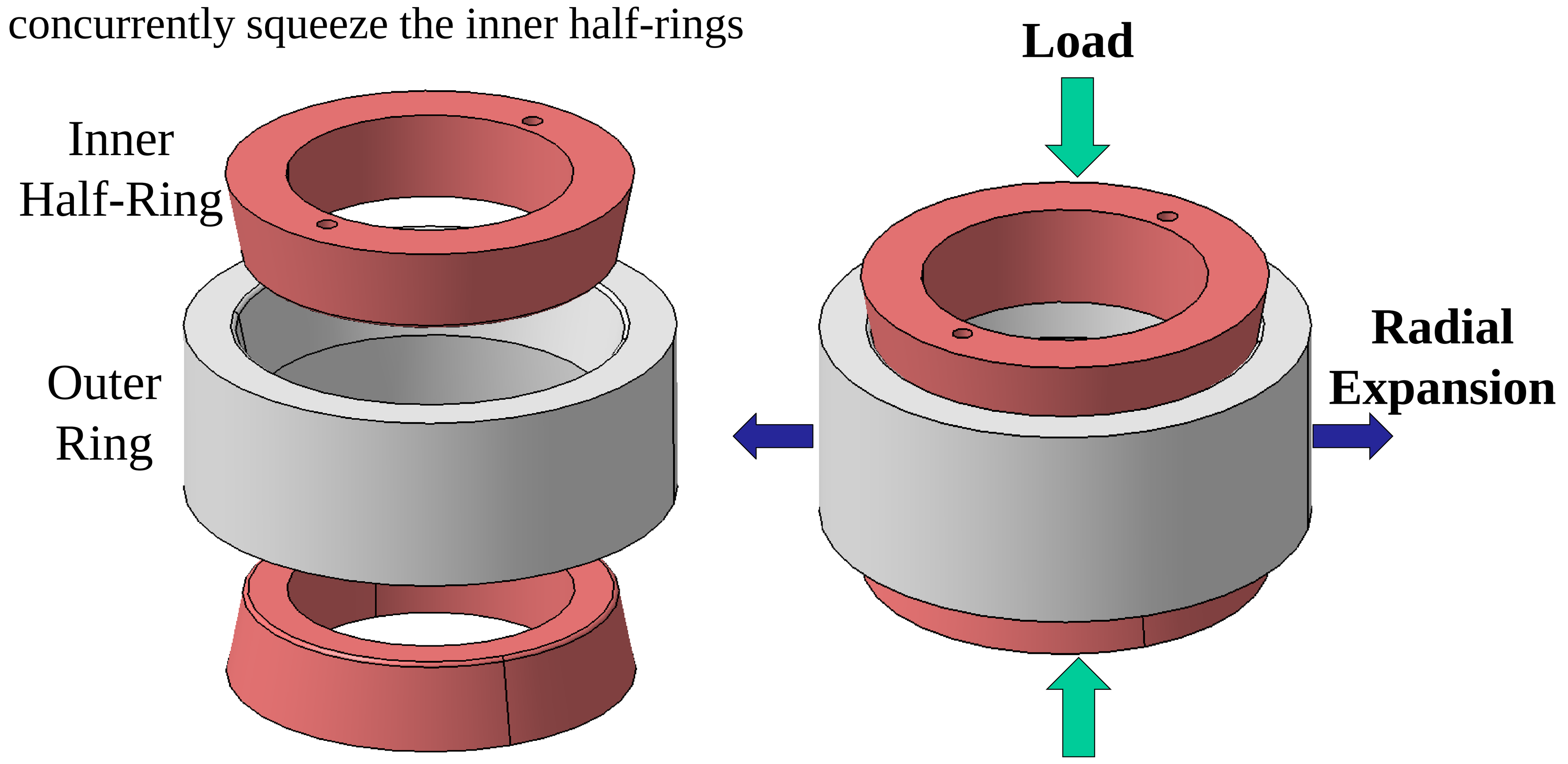
ABSTRACT

A device for investigating the degradation of the critical current density in MgB_2 wires and tapes as a function of circumferential strain has been designed. It will be integrated into the existing test facility (background field of 3 T, dc current power of 600 A, and conduction-cooled down to 4 K), thus determining the $J_c(B,T,\varepsilon_a)$ behavior of the superconductor under test. The spring geometry has been conceived for testing long length samples (>1 m) in a solenoid-like configuration, where a uniformly distributed circumferential strain (up to 1%) is applied to the MgB2 conductor through a ring-shape spring. The paper reports on the mechanical design, analytic calculations, and numerical simulations of the spring geometry. Moreover, experimental tests at room temperature and 77 K are performed on a mock-up model.

DESIGN AND WORKING PRINCIPLE

A The device consists essentially in two inner half-rings and an outer ring having conical surfaces, assembled together as shown in Fig. 1. Under an applied axial load, the wedging action tends to expand the outer ring and concurrently squeeze the inner half-rings



REQUIREMENTS

A We are interested in applying a variable circumferential strain to a maximum value of 1%, with a strain homogeneity of 1% with respect to the maximum strain value. Other challenging requirements concern the temperature homogeneity (< 0.2 K) and the length of the investigated sample (> 1 m). The device functional requirements are summarized in Table I.

Table I
Functional Requirements

Parameters	Value	Unit
Applied strain	≤ 1	%
Conductor length	> 1000	mm
Strain homogeneity	± 1	%
Temperature homogeneity	< 0.2	K
Actuator force	< 80000	N
Weight	< 10	kg

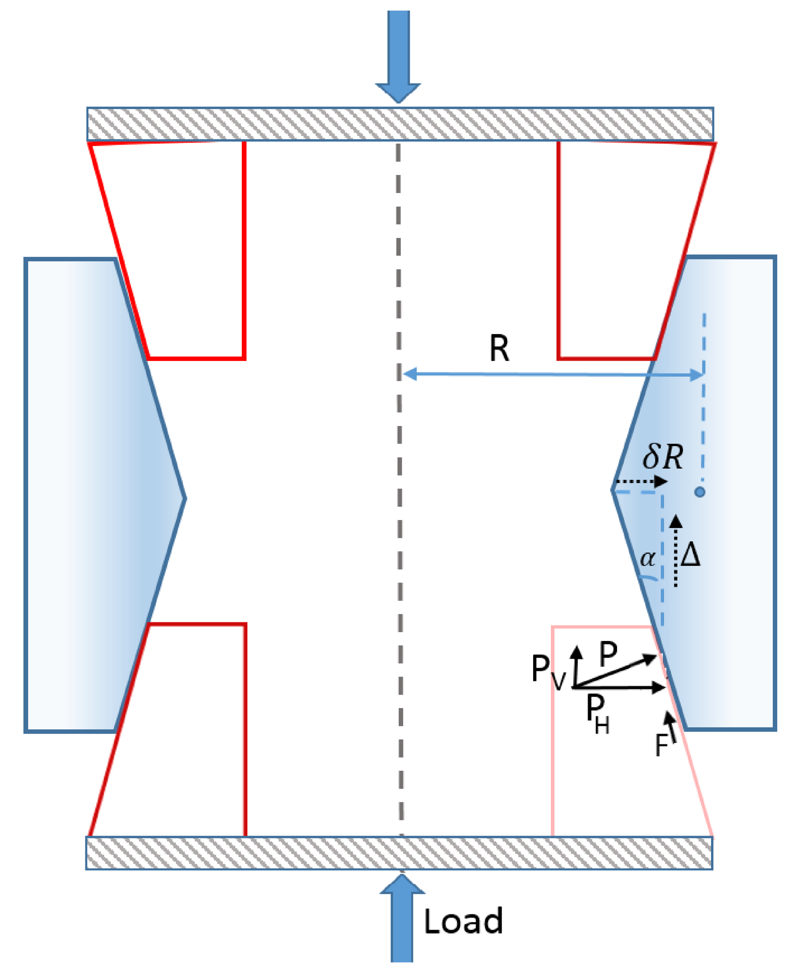
The strain device is to be integrated in the MgB2 test facility (worm bore of 350 mm)

Table II
Main Device Parameters

Variable	Symbol	Value
Radius	R_o R_i	150, 148 mm
Height	h	40-50 mm
Taper angle	α	10 deg
Vertical displacement	Δ	10-20 mm
Friction Coefficient	μ	0.1-0.2
Young Modulus	E	[3–8] GPa

FORCES CALCULATION

Considering the schematic representation, each conical surface of the ring elements may be considered as subject to a total normal force P distributed uniformly around the circumference and a frictional force F on the contact surface.



Assuming the spring is being compressed, the total radial force acting on the outer ring will be equal to:

$$P_H = 2(P\cos\alpha - F\sin\alpha)$$

and the radial load uniformly distributed along the perimeter of the ring is:

$$w = \frac{P_H}{2\pi R} = \frac{P(cos\alpha - \mu\sin\alpha)}{\pi R}$$

The applied axial load (L) during the compression stroke can be written as

$$L = P_V + F_V = P(\sin\alpha - \mu\cos\alpha)$$

$$\Rightarrow \quad P = \frac{L}{\sin\alpha - \mu\cos\alpha}.$$

The tensile stress on the outer ring (with A_o indicating its cross-sectional area) is:

$$\sigma_t = \frac{wR}{A_o} = \frac{P(\cos\alpha - \mu\sin\alpha)}{A_o\pi}$$

Now, by substituting P , the tensile stress can be expressed as:

$$\sigma_t = \frac{L}{\pi A_o}\frac{\cos\alpha - \mu\sin\alpha}{\sin\alpha - \mu\cos\alpha} = \frac{L\tan\alpha}{\pi A_o K} \quad \text{where:} \quad K = \frac{\tan\alpha(\mu + \tan\alpha)}{1 - \mu\tan\alpha}$$

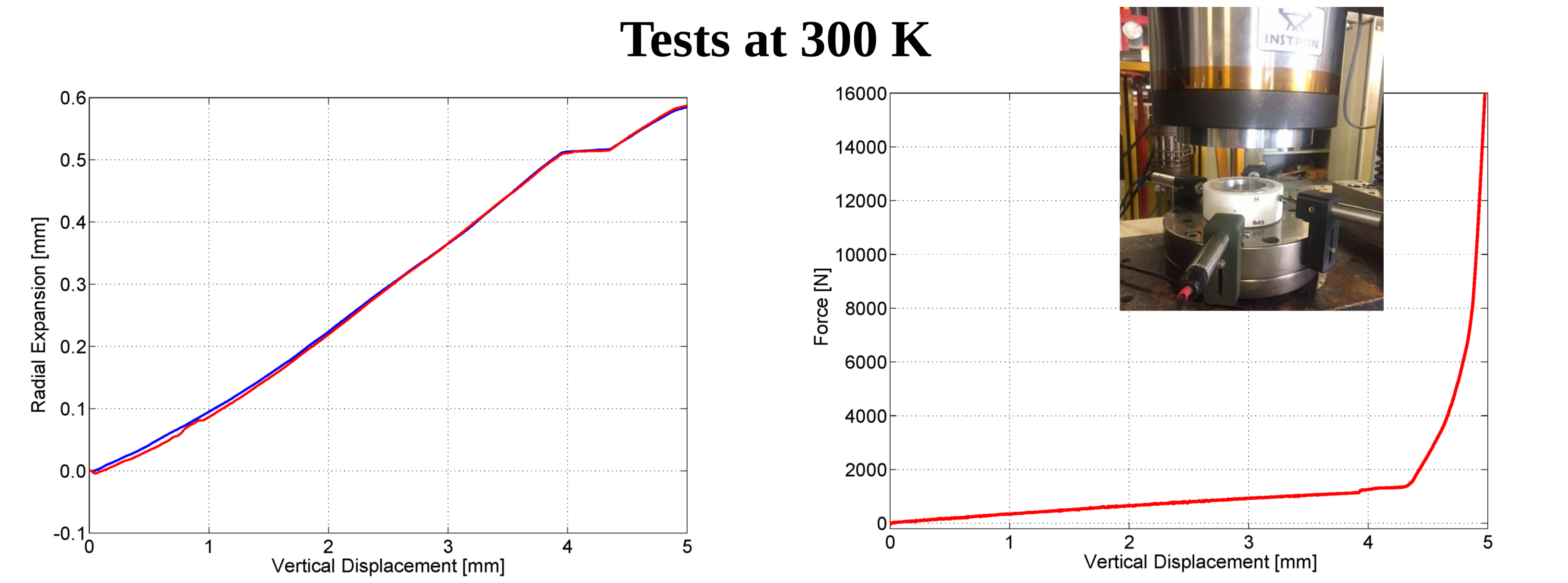
From the Hooke law: $\epsilon = \frac{\sigma_t}{E} = \frac{L\tan\alpha}{\pi EAK} \Rightarrow L = \frac{\epsilon\pi EAK}{\tan\alpha}$

The total axial deflection due to the outer ring: $\Delta = \frac{2\epsilon R}{\tan\alpha} = \frac{2\sigma_t R}{E\tan\alpha} \Rightarrow \Delta = \frac{2RL}{E\pi AK}$

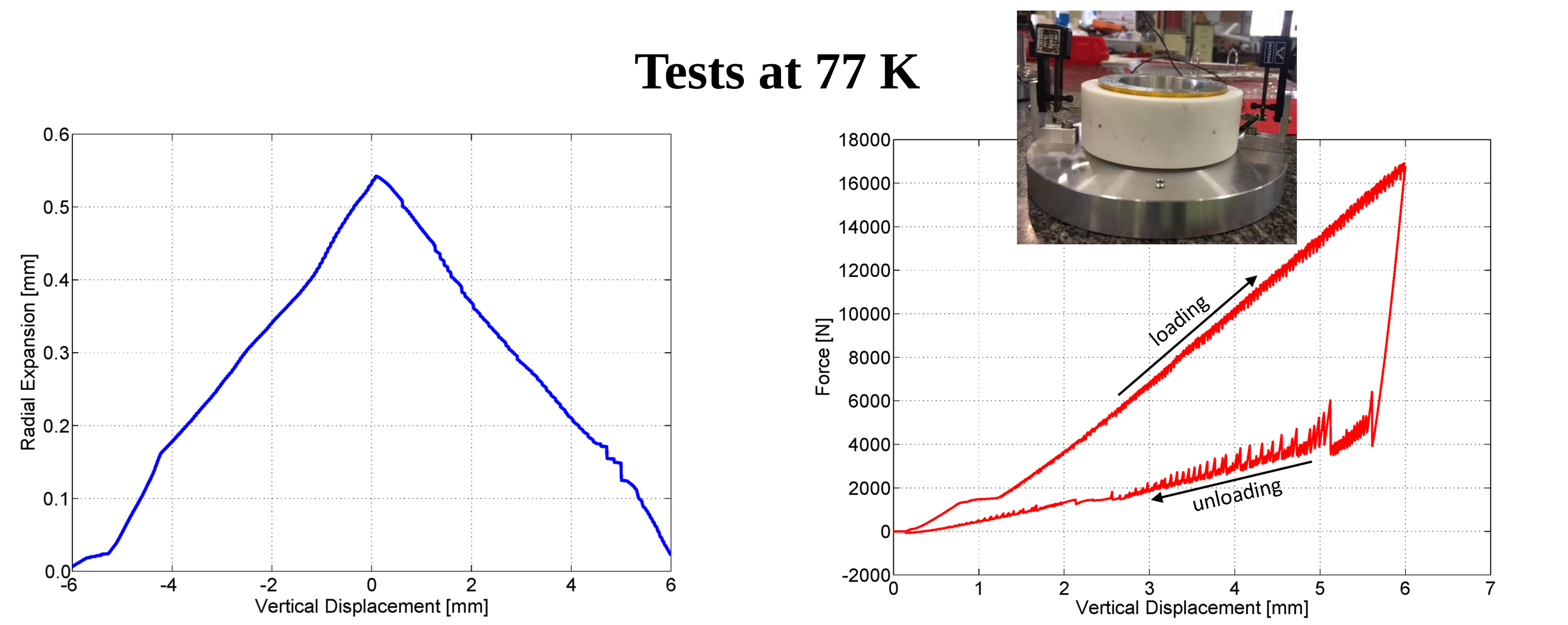
TESTS AND PARAMETERS VERIFICATION

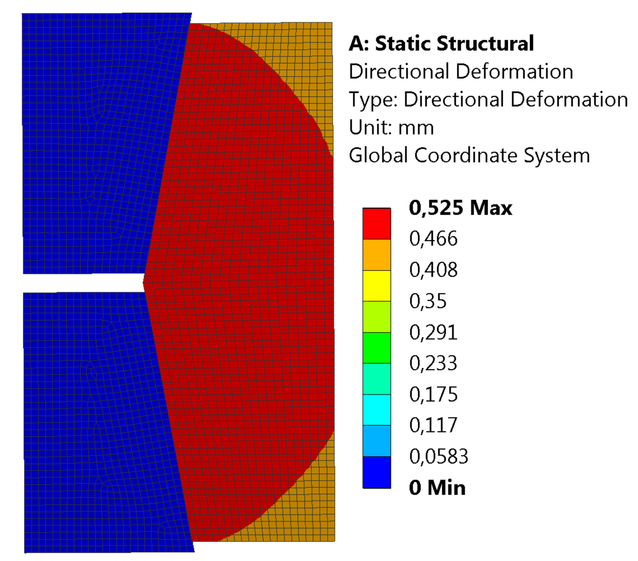
The test campaign is performed on a mock-up model (100 mm diameter) with the outer ring made of PTFE and the inner half-rings made of aluminum.

Tests at 300 K



Tests at 77 K





A dynamic friction coefficient of 0.1 and a modulus of elasticity of 3.3 Gpa were obtained. Using these values, the mock-up model has been simulated in Ansys.

CONCLUSION

Several experimental tests at room and cryogenic temperatures were performed on a mock-up model. The results have validated the design and have highlighted some critical points that should be carefully considered during the device construction. First, the **azimuthal uniformity of the ring expansion** depends on the fabrication precision of the rings (axisymmetric, taper angle, rugosity). Second, the **friction forces** play a crucial role in the device performance (better results by adding Kapton tape). The experimental tests also evidenced that the spring has to be **pretensioned with minimum 5% of the total spring travel**. For a maximum strain of 1% there was not a **permanent deformation/hysteretic behavior** of the outer ring. At 77 K the **stick and slip effect** is acceptable (more important during the spring unloading). On the basis of numerical simulations and experimental tests, we have concluded that this spring geometry is suitable for our variable-strain device and currently we are working on its construction.