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QUENCH AND SAFETY TESTS ON A TOROIDAL FIELD COIL OF TORE SUPRA

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QUENCH AND SAFETY TESTS ON A TOROIDAL FIELD COIL OF TORE SUPRA

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ABSTRACT

As a part of the safety analysis of the magnet, three quenches have been initiated in one of the TF coils in the Saclay test facility. While transporting a given current, the coil is insulated from the refrigerator : the temperatures of the helium and of the coil increase slowly on account of thermal losses. At the current sharing temperature a quench rapidly propagates and the protection system makes the coil discharge in the dump resistor. At three levels of current, electrical, thermal and hydraulic measurements have been performed. All these results are taken into account for the safety design of TORE SUPRA.

INTRODUCTION

The toroidal field of TORE SUPRA is provided by 18 superconducting coils. Each of them has been successfully tested in a special test facility at SACLAY [1]. These 18 coils are now at CADARACHE, the complete TF system has been assembled and is now ready for the cooling down scheduled at the beginning of December 1987.

A special prototype coil was tested in March 1985 whose results have been already reported [1]. All the sensors were then removed, the coil being finally machined to become a spare coil of the TF coil magnet. Finally a series of global safety tests have been carried out on this coil at Saclay during October 1986.

I. GENERAL PURPOSE OF THE TESTS

The main purpose of the tests was to give information on the behaviour of a toroidal field coil in case of quench. This had been already done on the prototype coil by initiating with a heater, a very local transition. It was in fact quite difficult to induce it because of the very good stabilizing properties of helium II.

In this second series of test the purpose was very different : it was to test the general safety conception of TORE SUPRA in case of a quench by initiating a complete and very rapid transition all over the coil. In doing so the Joule heating is transferred in a short time to helium with a very high level of power. The quench was induced by the following procedure :

- the coil is insulated from the refrigerator and heats up because of thermal losses.
- the helium pressure is kept constant at a value of 0.7 MPa thanks to a spring loaded safety valve. In these conditions, it is possible to keep a sufficiently high value for the helium density, for instance 77.4 kg/m^3 at 7.5 K in comparison with 148 kg/m^3 at 1.8K and 0.1 MPa, which is the operating value.
- the current is increased in the coil up to a given value ;
- when the current sharing temperature is reached, a quench occurs and is detected by the safety system. The current is then discharged through the dump resistor.

In these conditions it has been possible to gain further information about the quench propagation inside the coil. Moreover the hydraulics of the helium evacuation circuit has been investigated in details. This has been possible thanks to pressure and temperature sensors installed all along the external cryogenic circuit of the coil.

Measurements of pressures and flow rate during quenches have led to a better understanding of the behaviour of the different safety valves and have provided characteristics to calculate the maximum pressure inside the coil in case of quench on TORE SUPRA.

II DESCRIPTION OF HYDRAULIC AND ELECTRICAL CIRCUITS

The electrical circuit is presented in Fig. 1. In case of quench, the current breaker CB opens and the magnetic energy of the coil is dumped through the resistor Rs connected in series with the coil.

Quench detection

A special pick up coil has been wound on the external part of the coil thick casing. The quench detection signal ΔV is elaborated by opposing the coil voltage and this pick up coil voltage multiplicated by a correction factor.

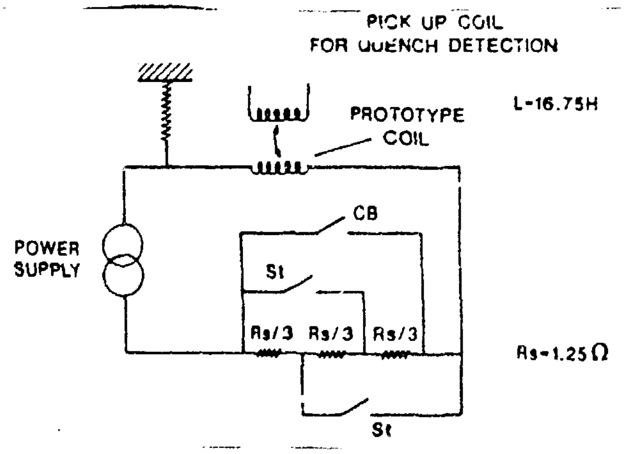

Fig.1. Electrical circuit

The hydraulic circuit of the prototype coil is presented in Fig.2.

As soon as the atmospheric pressure is exceeded, the cold valve CV opens and helium flows out through the helium evacuation circuit. Beyond 0.7 Mpa, SV1 opens and some helium is continuously evacuated outside. When the adjusted pressure of 1.14 MPa for SV2 is exceeded, SV2 [2] opens inducing at the same time the closing of SV1.

In case of overpressure the safety burst disk, breaks at a higher pressure of 1.8 MPa and allows helium evacuation .

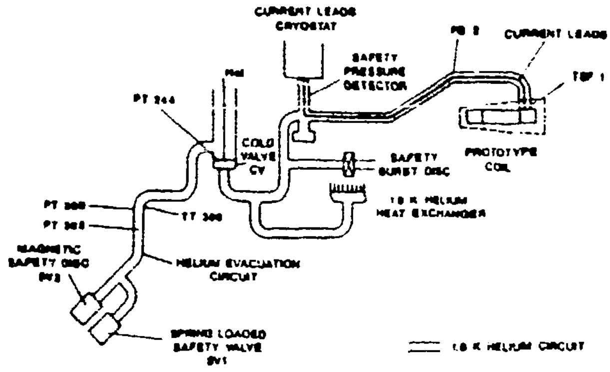

Fig.2. Hydraulic circuit

sensors

temperature sensors :

TSF1 at the helium outlet of the coil
TT300 on the helium evacuation circuit

Pressure sensors :

PB2 at the helium outlet of the coil
PT244 near the cold valve CV
PT300 on the helium evacuation circuit
PT302 Pitot tube on the helium evacuation circuit

III ELECTRICAL RESULTS AND ANALYSIS

Three experiments have been performed for three values of current in the coil : 650 A, 750 A and 1000A to be compared to the nominal current I_0 =1400 A.

It was expected to observe a very fast(a few seconds) and global transition of the whole coil because every point in the coil is at a temperature near the current sharing temperature. Actually by comparing the experimental results to the measurements with a quench propagation code, it appears that the coil is completely normal within about 3 seconds. For the specific heat of helium, we assumed in the computer code a constant pressure of 10 bars all along the quench, which is only an average on the time.

It is to be noted that the influence of the field decrease on the copper resistivity has been taken into account. The results show a strong dependance of the propagation phase, on the level of current.

1) Results of the test at 750 A (Fig.3)

The decrease of the copper magnetoresistance can be observed just at the end of the propagation phase. This decrease is then balanced by the increase of the copper resistivity due to temperature increase : the coil resistance remains nearly constant.

2) Results of the test at 1000 A (Fig.3)

The transition of the whole coil takes less than 2 seconds after the beginning of the discharge. Then a flat top can be observed on the resistance curve, which means that the coil is completely resistive with an overall temperature less than 20 K. Then the coil resistance increases with the temperature. The calculations are somewhat shifted on the right in comparison with experimental results which means that the experimental transition has been somewhat faster than the 3 seconds taken in the calculations.

TABLE 1
Overall results for the three quenches

I_0 (A)	650	750	1000
Ee (MJ)	0.6	0.91	2.1
Et (MJ)	0.68	0.93	1.9
We (kW)	99	155	357
Wt (kW)	118	159	303

I_0 current level at the beginning of the discharge
Ee Energy dissipated inside the coil(experimental)
Et Energy dissipated inside the coil(computed)
We maximum power during the discharge(experimental)
Wt maximum power during the discharge(computed)

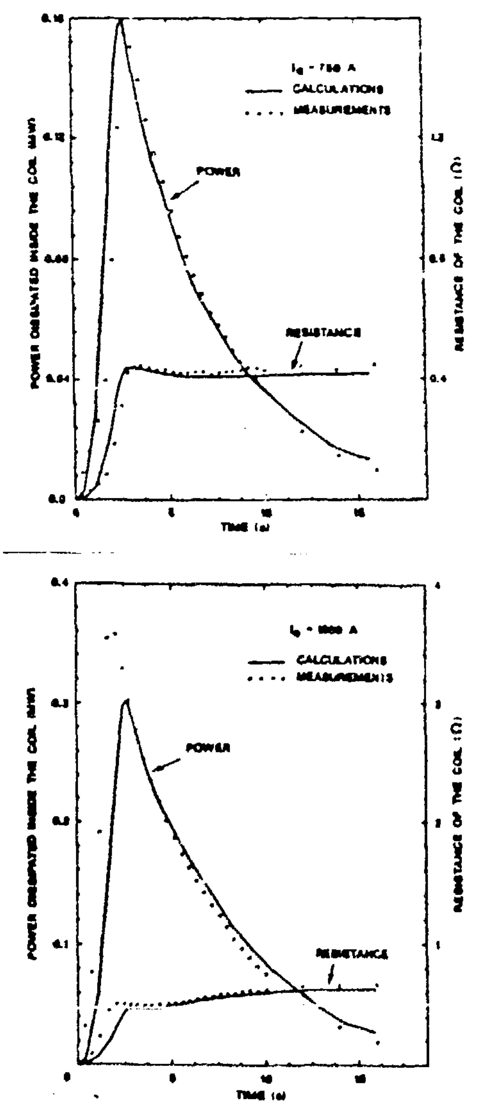

Fig.3. Electrical results at 750A and 1000A

IV THERMAL-HYDRAULIC RESULTS AND ANALYSIS

1) general results

The primary interest of these tests has been to understand the relative behaviour of the two different safety valves. The results show that for $I_0 \geq 750$ A, the spring loaded safety valve does not open fast enough to limit the pressure increase. As a consequence, the pressure set of the magnetic safety disc (1.14 MPa) is reached rapidly, causing this valve to open and hence limiting efficiently the pressure increase.

A special test with I_0 = 650 A and with a pressure set of the magnetic disc at 1.34 MPa was carried out in order to use only the spring valve as safety valve. This test confirmed the fact that the opening speed of this valve was too low to work efficiently at high rate of pressure increase. In the following, only results of tests at 750 and 1000 A are considered as they correspond to the same behaviour of the safety valves as in a quench at nominal current in TORE SUPRA.

2) Results of tests at 750 A and 1000 A.

Figure 4 give the pressure at the coil output PB2, the pressure upstream the safety valves PT300, the mass flow rate D, for the test at 750'. Figure 5 show the same quantities for the test at 10 A. The main points to be noted about the results : :

- the opening of the magnetic safety disc leads to a considerable increase of the mass flow rate (increase of the output aperture)
- after this opening, PT300 decreases but remains nevertheless at a relatively high value.
- if at 750 A, the opening of the magnetic safety disc leads to a decrease of PB2, this is no more the case at 1000 A for which the pressure still increases.

3) Theoretical analysis

In order to understand the different results as well as to be able to predict the behaviour of the fluid in case of a quench on TORE SUPRA, a thermal-hydraulic model has been developped [3]. The principle of the HETOR code is to determine the pressure, the temperature and the mass flow rate everywhere in the fluid, from the initial conditions and the electrical power We(t) dissipated inside the coil. The main characteristics of the code are given below :

- at each time step, the calculations are performed using stationary flows through the pipes(this assumption leads to a drastic simplification and is possible because of the short length of pipe ~ 10 m)
- a computer code is used as subroutine for thermodynamic helium properties.
- the pressure drop coefficients in the pipes as well as the heat transfer coefficient in the exhaust pipe, almost at room temperature, are determined using experimental results.
- two models are used for the coil : the "one volume" model in which the temperature is uniform inside the whole coil, and the "two volumes" model in which only a part (increasing) of the coil is heated with We, the other part being isentropically compressed. The difference between the two models lies in the temperature of the ejected fluid.
- according to the experimental results, the safety valves behaviour is simulated in a very simple way : let Pset be the pressure set of the magnetic safety disc, then for P < Pset:D = 0, and as soon as P ≥ Pset, the valve is assumed to be totally open.
- the code can take into account a shock wave.

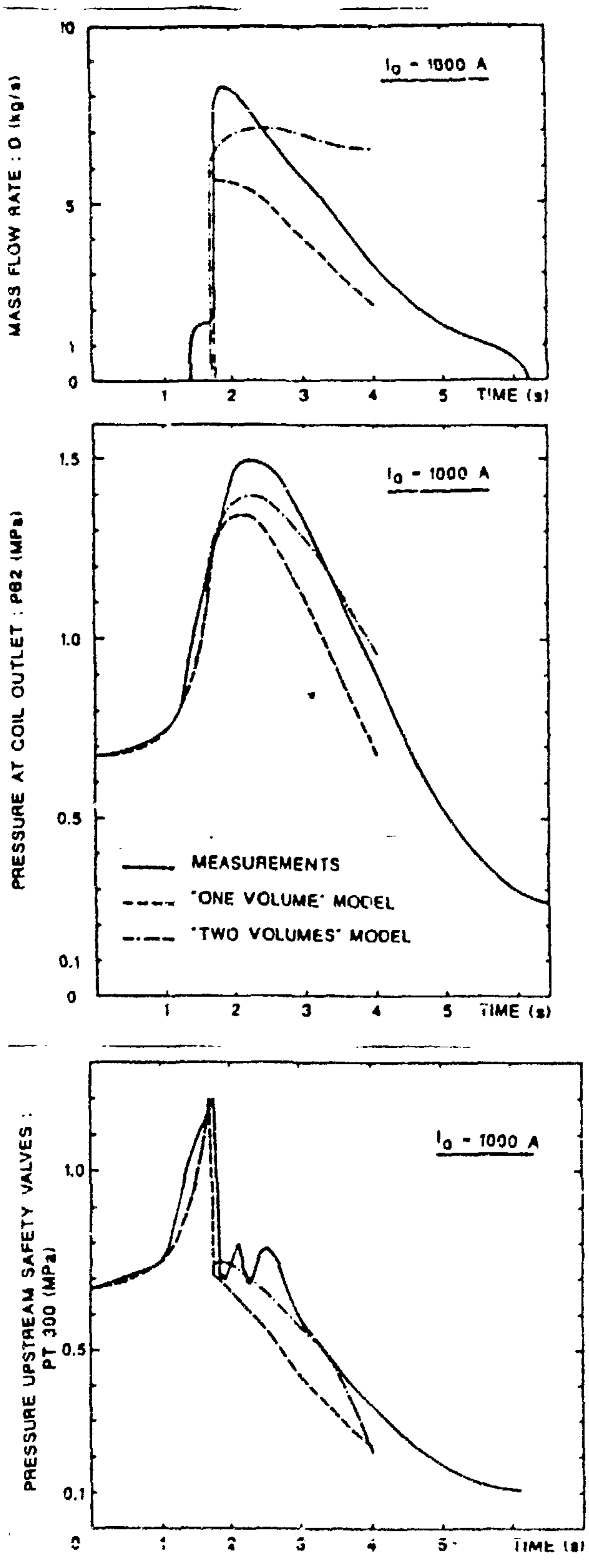

Fig.5 . Hydraulic results at 1000A.

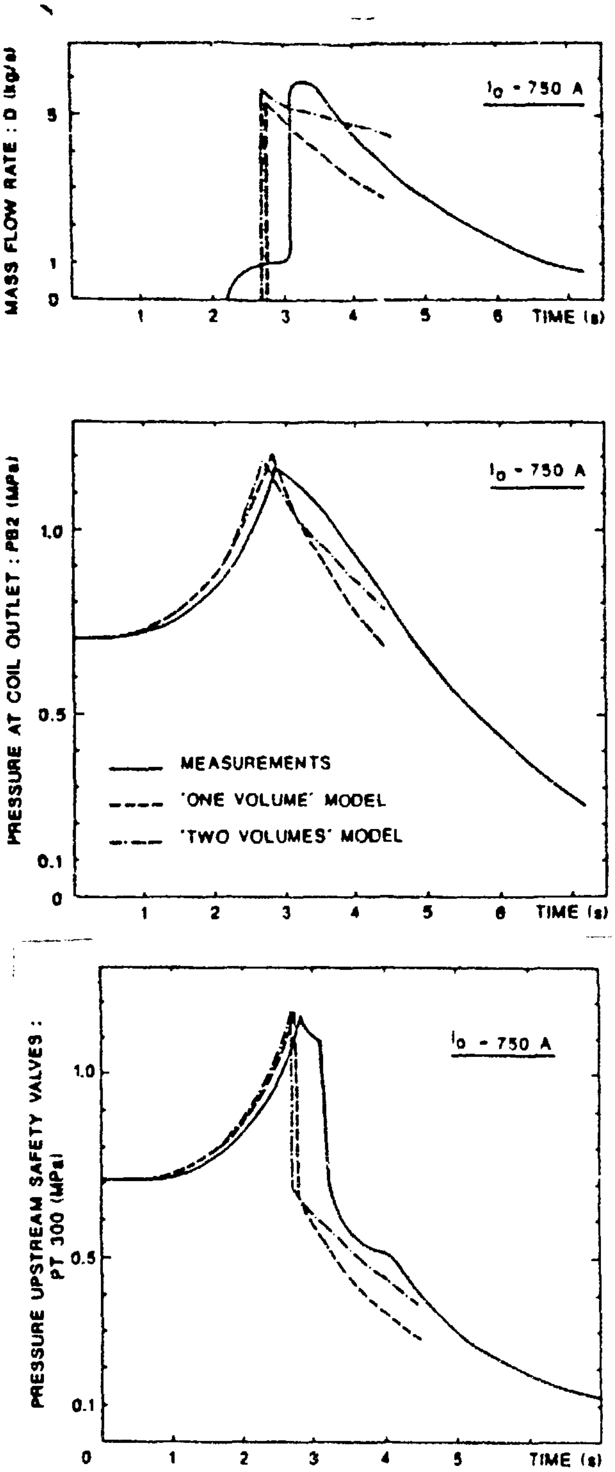

Fig.4 . Hydraulic results at 750A.

The results obtained with the HETOR code are plotted in Figures 4 and 5. for comparison with the measurements. Several remarks have to be made.

- neglecting the effect of the spring valve, the code predicts quite well the evolution of the different pressures and the mass flow rate(see §IV.2). One will note particularly the different behaviours of PB2 at 750 A and 1000 A.
- the high value of PT300, which is also found by the code, is due to the fact that the sound velocity is reached at the level of the magnetic safety disc. This phenomena is intensified by the acceleration of the fluid in the room temperature pipes.
- in the very first seconds following the opening of the magnetic safety disc, the "two volumes" model gives better results which is confirmed by looking at the coil outlet temperature TSF1 (not given in this paper [3]).

V. EXPECTED CHARACTERISTICS FOR TORE SUPRA

With the same model, it has been possible to calculate the expected characteristics for TORE SUPRA. Each coil is associated in series to a 2.5Ω resistance, the middle point of which is grounded through a 5.Ω resistance. Assuming an instantaneous and complete transition of one coil, which is very pessimistic, we obtain :

Et = 13 MJ
Wt = 1.09 MW

The resistance of the coil at the end of the discharge is 2.7 Ω.

In these conditions the maximum expected pressure is about 3 MPa, which is acceptable ; it takes place 1.1 second after the beginning of the discharge. The maximum flow rate is 16 kg/s.

CONCLUSION

By these tests, it has been possible to check the general safety conception of TORE SUPRA on a model of the same size. In particular it has been demonstrated that the energy extraction in case of quench was fast enough to limit the pressure increase inside the vessel to an acceptable level.

References

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[2] Magnetic safety disc:DISPORA(C) from ADAREG(FRANCE)

[3] D.Ciazynski CEA Internal Report DRFC TS-42.87.01