SLHC-PP

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The Preparatory Phase of the Large Hadron Collider upgrade (SLHC-PP) is a project co-funded by the European Commission in its 7th Framework Programme under the Grant Agreement n° 212114. SLHC-PP began in April 2008 and will run for 3 years.

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1. EXECUTIVE SUMMARY

In the progress report for the second year, it was explained that the engineering design challenges require model magnet assemblies and additional tests including the validation of the porous cable insulation, the validation of a more porous ground plane insulation scheme, and the testing of the collaring procedure that also allows the positioning of the coil-pack in horizontal position [2].

The bath temperature of the coolant in the MQXC magnets is estimated to be 1.96 K, which is at the maximum of the thermal conductivity of superfluid helium. Because the thermal conductivity drops sharply above 1.96 K, the additional temperature gradient to the heat exchanger has to be kept at a minimum. Therefore a more porous insulation scheme for the superconducting cable was proposed [8]. This porous insulation has a considerably lower elastic modulus with respect to the proven LHC (main magnet) insulation scheme. This was shown with so-called 10-stack tests and with the arch testing of trial coil winding at CEA/Saclay (see report on Deliverable 6.2.2). These tests show, however, an offset (with respect to the LHC standard insulation) in the thickness of the cable insulation under the assumed pressure after cooldown to cryogenic temperatures. This is one of the reasons for the construction of an "instrumented collar pack," which allows the measurement of the resulting coil stress under realistic assembly conditions. An artists view of the collar pack is shown in Fig. 1.

The instrumented collar pack is also needed for the qualification of the assembly and collaring procedure. In order to keep the 4-fould symmetry, necessary for a good field quality in the quadrupole magnet, a spring-loaded, split assembly mandrel was developed and procured from European industry.

Moreover, the instrumented collar pack can be cooled to cryogenic temperatures in order to study the loss of pre-stress. The results of these tests are crucial for the production of magnet coils, because both the coil size prior to the collaring and the elastic modulus must be known in order to calculate the required coil shimming. This shimming will guarantee the appropriate pre-stress in the coil after cooldown and excitation.

In order to allow the percolation of helium into the superconducting coil blocks, the ground plane insulation was also redesigned. The second instrumented collar pack serves for heat-transfer measurements and for the experimental validation of this new ground plane insulation [1].

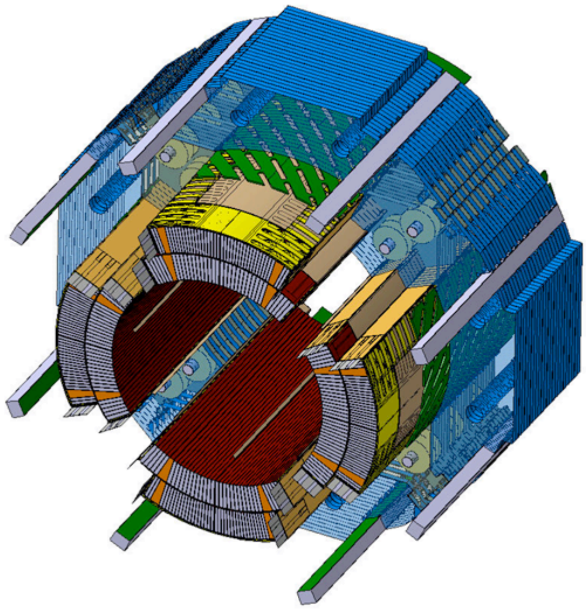


Figure 1: Three-dimensional rendering of the collar pack, showing the superconducting coil, ground plane insulation, collar packs and tie rods.

During the initial compression, each coil will be squeezed by approximately 2.5 mm azimuthally. After the keys have been pushed into the collars, the mandrel radius must be further reduced to allow it be extracted from the assembly. The roller bearings allow the extraction of the central port and therefore the extraction of the entire mandrel without damaging the coil insulation. This is an important development which was previously not required because the movement with the LHC style insulation and coil dimensions were considerably smaller.

A 150 mm long model mandrel was built and tested, (see Figs. 2 and 3) the full length, 1.8 m long mandrel, his being procured from European industry.

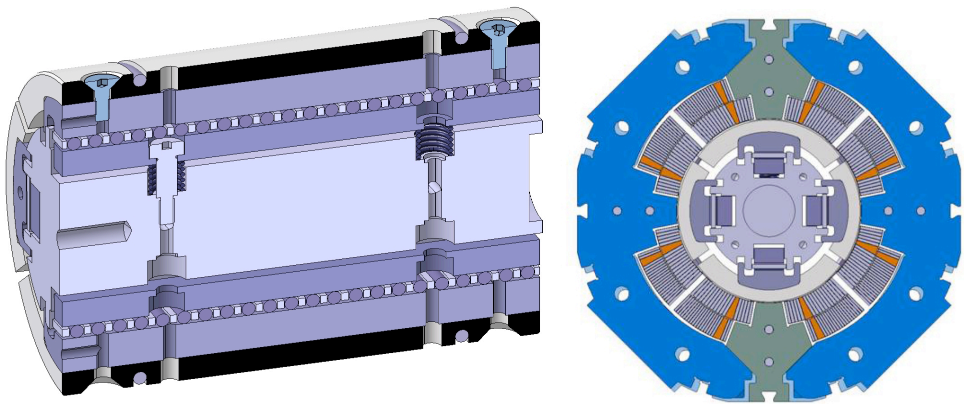


Figure 2: Left: Longitudinal section of the split assembly mandrel. Right: Cross section of the mandrel, coil and collar pack

Figure 3: Split mandrel procured from European Industry

2. HEAT TRANSFER STUDIES AND MODEL VALIDATION

Simulations with the FLUKA code give the power deposition distribution over the magnets in 3D space [5];. The worst-case position in longitudinal direction, where the total power per meter of magnet cross-section is at its peak value, is used in heat transfer calculations; see Fig. 4. To be able to simulate these volumetric power densities in an experiment, heaters that can be individually fired must be placed at strategic places, see Fig. 5.

Since the numerical COMSOL model shows that the enhanced ground insulation has a strong influence on the temperature distribution (and thus the temperature gradients), the positions of temperature sensors are obtained from these results. In one instrumented collar pack, several schemes can be analysed, although redundancy must be achieved. The influence of gravity is neglected, but measurements can be setup horizontally as well as vertically. Since only the collar pack, and not the complete magnet cross-section is tested, the thermal boundary conditions on the collar's outer diameter are the fixed bath temperature. Fig. 5 shows where the main differences in temperature distribution and heat fluxes will occur if changes in the thermal design are made.

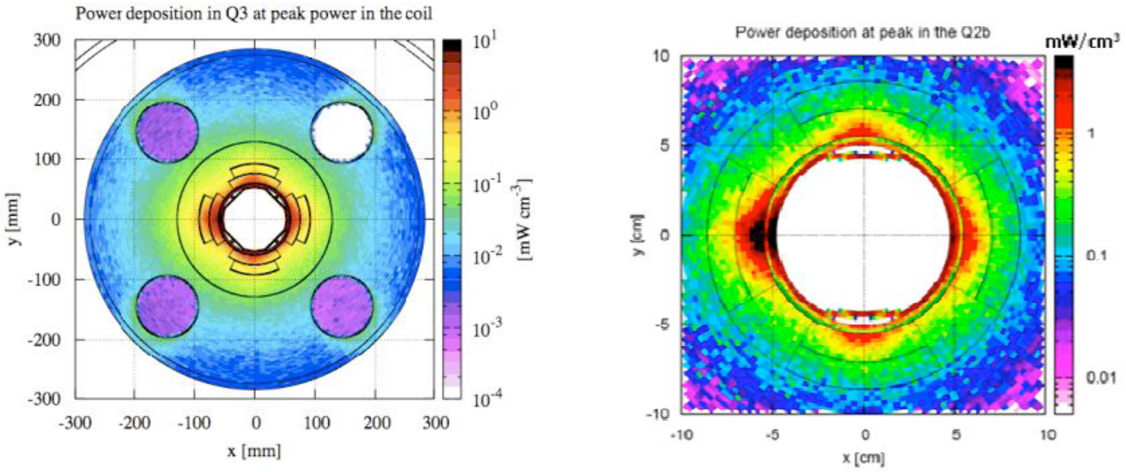


Figure 4: Heat deposition (worst case) in the quadrupole magnets of the inner triplet

When the new ground insulation is used, heat can flow radially outward from the outer layer through the helium channels in the fishbone and through the holes in the stainless steel protection sheet (collaring shoe). When the classical insulation scheme is used, four layers of Kapton block the heat flow, and therefore the energy must be extracted by solid conduction through this layer. Another possible path for heat extraction is via the helium channels towards the inner layer coil, via the annulus and then outward via the collar nose. These two different paths therefore require temperature sensors at positions shown in Fig.5.

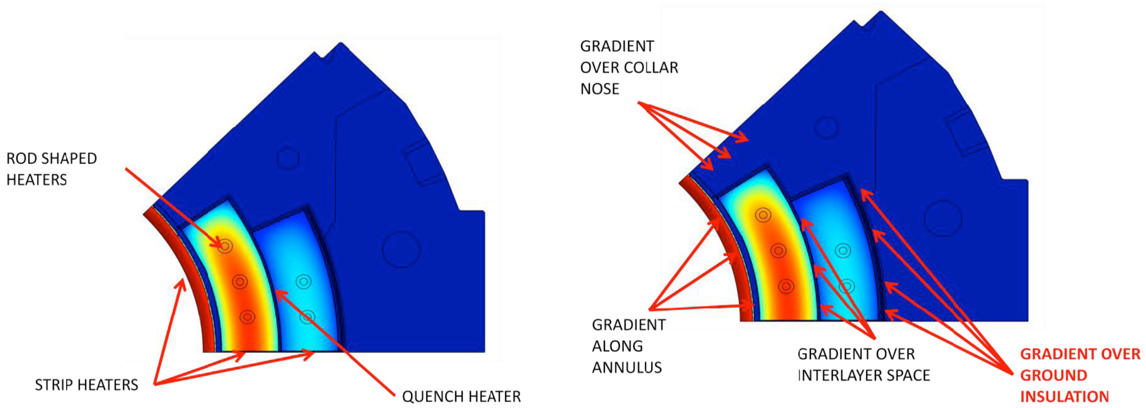


Figure 5: Heat distribution in the cross section of the collar pack when strip and rod shaped heaters are powered.

The influence of a wavy shaped quench heater is especially noted at the interlayer thermal behaviour. Because eight different schemes do not allow for redundancy in the same experimental setup, two different experimental setups are realized in one collar pack. As the interlayer heat transfer is considered to be of least interest, all parts of the collar pack will be equipped with the new wavy shaped quench heater. Fig. 6 shows how to distribute the schemes such that redundancy is taken into account.

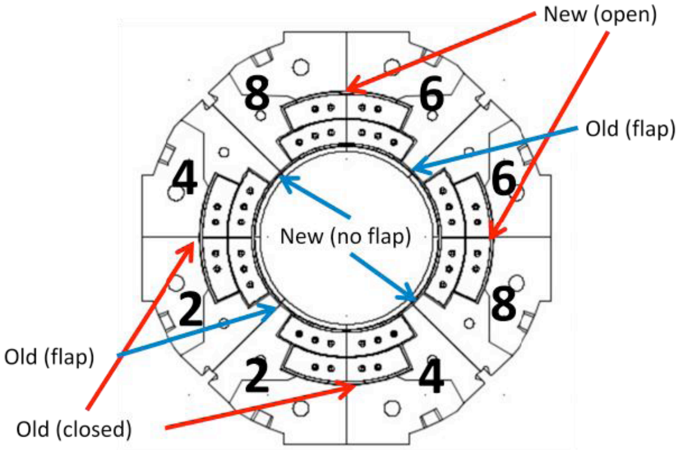
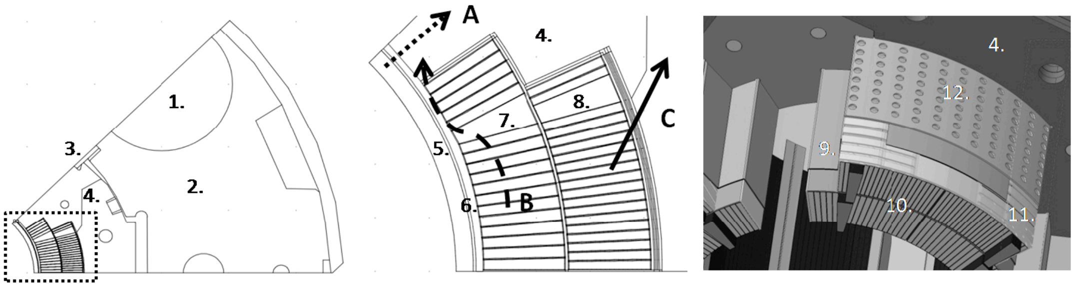


Figure 6: Layout of the insulation scheme, to have redundant measurements on both the classical as well as the new ground-plane insulation schemes.

3. ASSEMBLY OF COLLAR PACK

Fig. 7 (right) shows the new ground plane insulation and the role it plays for the heat exchange along path C shown in Fig. 7 (middle).



1. Heat exchanger (sink)
2. Iron yoke
3. Key
4. Stainless steel collar
5. Beam pipe and insulation
6. Helium annulus
7. Inner layer coil + Cu wedge
8. Outer layer coil + Cu wedge
9. Ground insulation
10. Quench heaters
11. Fishbone
12. Protection sheet

Figure 7: The role of the new ground plane insulation (right) for the heat transfer along path C (middle).

The ground plane insulation, shown in Fig. 7 (right), is identical to the long magnets and must be pre-formed in a dedicated mould, shown in Fig. 8. The midplane shim of the invar arches is also used for the first assembly and cooldown test and will be replaced by strip heaters, which can be fired individually for every layer and pole. The collars are from the series production for the long model magnets, see report on Deliverable 6.3.2.

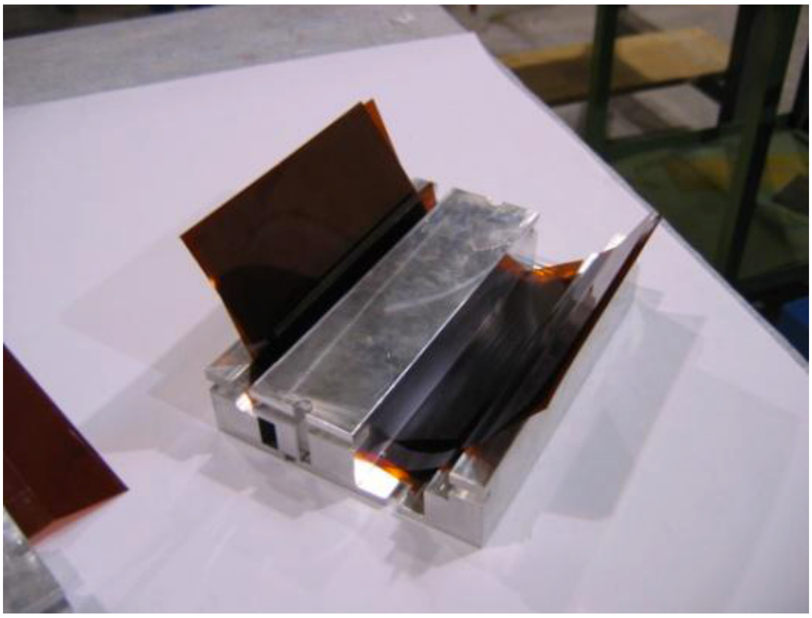


Figure 8: Pre-forming of Kapton sheets for the ground plane insulation

Fig. 9 (left) shows the pre-assembled collar pack used for thermal conductivity measurements. Fig. 9 (right) shows the assembly in the collaring press, after the keys have been inserted; see also report on Deliverable 6.3.2. The main focus of this assembly lies on the behaviour of the ground insulation scheme. Therefore solid blocks of invar are be used instead of the superconducting coils. In the invar block, only thermal conduction plays a role and the understanding of the complex behaviour of (superfluid) helium in (micro)-channels is not required. The use of invar has an additional benefit: the thermal contraction of this material is much smaller than the thermal contraction of the other materials (stainless steel collars) used in the construction of the mock-up, such that pressure can be generated artificially during cooldown, without the need of obtaining 50 MPa under the collaring press.

The second collar pack requires special collars for the routing of the instrumentation. Both strain gauges and capacitive pressure transducers are used for measuring the residual pre-stress after the removing from the collaring press and cooldown to cryogenic temperatures. This type of transducers is produced on-site at CERN and each gauge has to be calibrated at both room and cryogenic (77 K) temperatures. A special setup has been developed for the calibration at cryogenic temperature on the tensile machine delivering 0.1 to 200 kN of force. The capacitance of the transducer is changing during cooldown (so-called apparent capacitance). So the output signal of unloaded transducer (zero balancing value) is changing as well.

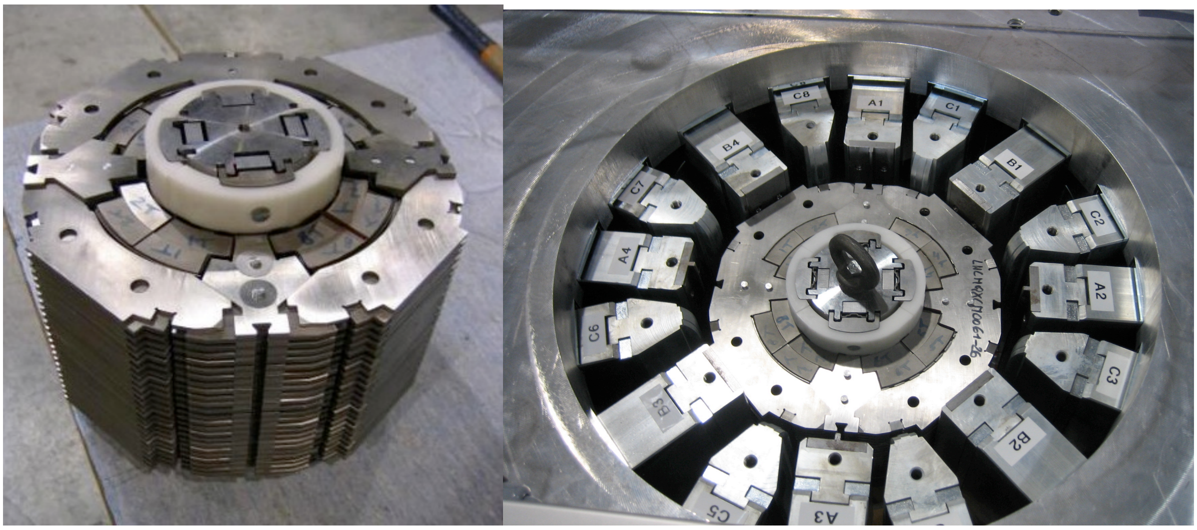


Figure 9: Left: Collar pack for heat transfer measurements after pre-assembly on the collapsible assembly mandrel. Right: Collar pack in the press after the insertion of the keys.

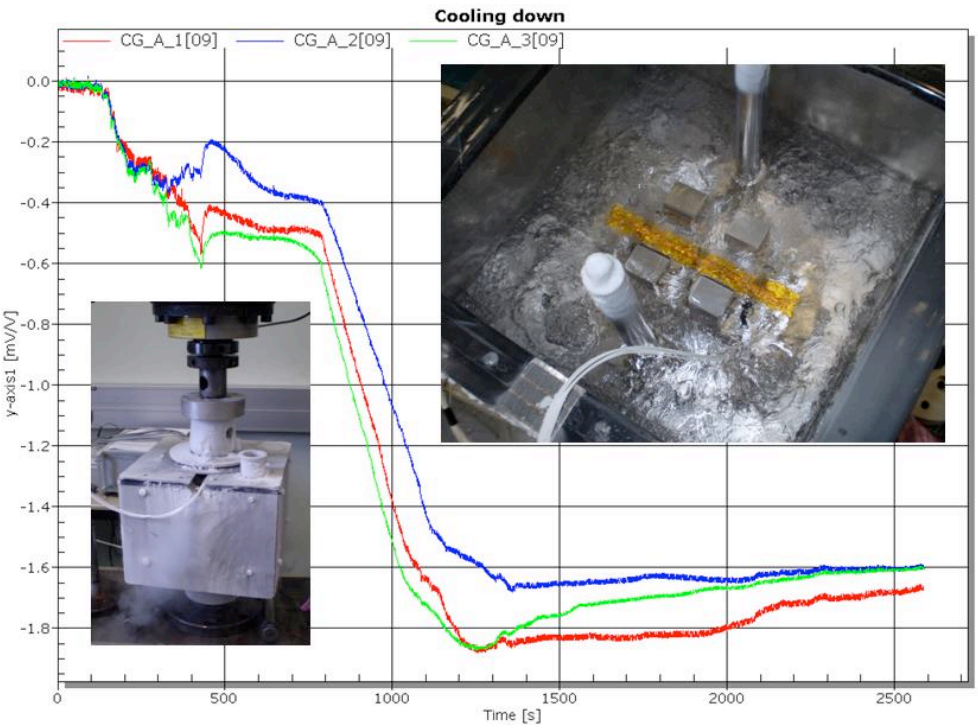


Figure 10: Measurement versus time during the cooldown of the gauges.

Once the system has reached the equilibrium three load cycles up to 90 kN (129 MPa) were applied to the transducer. Then the part of the setup that is inside the Dewar vessel was rotated to 90 degrees around its axis and the load cycles were repeated. The calibration curves are shown in Fig. 11 (left).

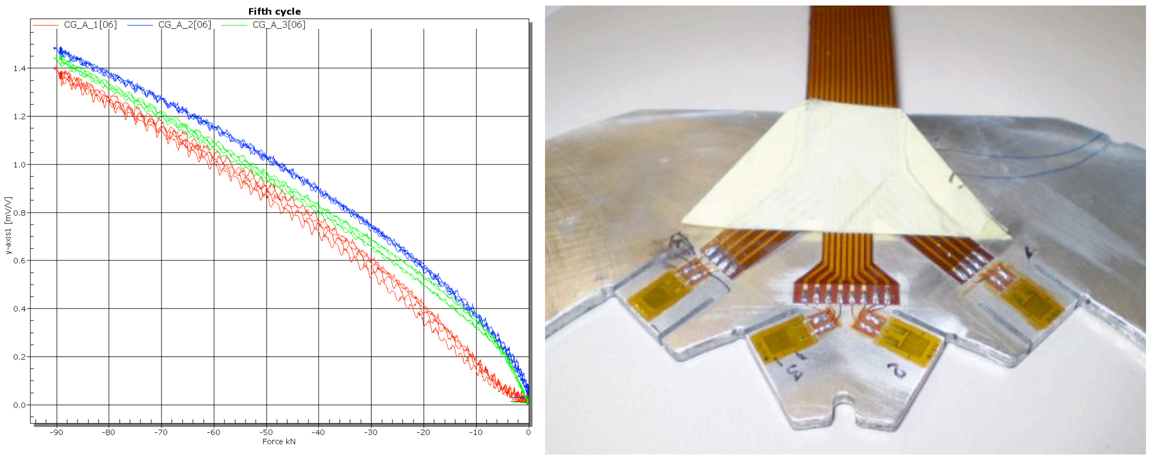


Figure 11: Left: Calibration curve for the gauges. Right: Gauges mounted on the instrumented collars of MQXC.

This test of this instrumented collar pack with capacitive pressure transducers is important for the validation of the mechanical calculations presented in the report of Deliverable 6.2.2. Assembly of this collar pack depends on the completion of the size and elastic modulus measurements of the coil stacks; see also report on Deliverable 6.2.2. Now with this heavy tooling fully commissioned, CERN will proceed to assemble the second collar pack by the end of May 2011.

4. CONCLUSIONS

Before the assembly of the 2-m-long model magnets can be completed, the assembly procedure must be validated with the instrumented collar packs described in this report. With the measurements of the elastic modulus and the coil size at the requested 50 MPa pre-stress, the necessary shim size can be calculated. However, this also requires the knowledge of the loss of pre-stress due to plastic deformations in the keyways of the collars. To establish this loss of pre-stress is the aim of the mechanical collar pack. The material for this pack has been procured from European industry, the assembly relies, however, on the full commissioning of the E-modulus tester and the measurements of all coil stacks.

The MQXC model magnet features novel ideas to improve the heat transfer from the magnets cold bore to the bayonet heat exchanger. The experimental verification of the numerical simulations for the heat transfer is the aim of the second (thermal) collar pack. The pre-forming of the ground plane insulation for this collar pack in a dedicated curing mold also validated the production technique for the long magnets. The collar pack is now fully assembled and will be cold-tested in May 2011.

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