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TESTS OF INDUSTRIAL ETHYLENE-PROPYLENE RUBBER HIGH VOLTAGE CABLE FOR CRYOGENIC USE

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Abstract

At the beginning of 1999 the University of California at Los Angeles has received a prototype High Voltage Cryogenic Cable supplied free of charge by Pirelli. The cable is intended for more than ten years of service at 100 kV D.C. and liquid argon temperature. The cable uses an all welded construction, which is axially tight and free of ionizable voids. The cable was submitted to a number of mechanical and electrical tests as described below.

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1. Introduction

Upon reception of the cable the main problem was the one of checking its quality, because UCLA lacked at CERN both the manpower and the equipment necessary for such tests. In particular UCLA was concerned by certain safety aspects of the tests and by a limited experience in this field. In due time, and with the assistance of CERN, all these problems were solved.

2. Cable design

The cable is built around a central stainless steel wire surrounded by three co-extruded successive layers of Ethylene-Propylene Rubber (EPR), respectively conductive, insulating and again conductive. The all welded construction thus obtained is axially tight and free of ionizable voids. The cable construction is shown in figure 1 in cross section.

3. Mechanical tests at cryogenic temperature (liquid nitrogen)

The cable was tested for elongation and Young's modulus. In a first test under axial tension the end fixations produced premature cracks on the outer surface. When the gripping parts were better rounded and smoothed the inconvenience gave way to slippage of the cable in the fixations. Given the considerable amount of work involved in modifying the tooling and the uncertainty of the results, this test was replaced by a flexural one done with less precise but much simpler equipment (fig. 2). We have obtained an elongation of 2.5 to 3%, which compares satisfactorily with the very limited elasticity of most plastic materials at low temperatures. This shows EPR to be not only a good insulator but also a convenient material for a cryogenic environment.

As for Young's modulus, we have calculated from the same test a value around 57,000 Kg/cm², i.e. of the same order of magnitude as the one of glass fiber reinforced plastics at ambient temperature. This result shows that a cryogenic cable, although retaining a sufficient flexibility at the temperature of operation, is capable of transmitting sizable forces to the adjacent structures. A good compliance between fixed points should be aimed at, e.g. avoiding straight lines and the associated high axial forces.

4. Room temperature electrical tests

The first tests were made at room temperature on a short length of cable (about 5 m) and at the maximum voltage directly available from the supply without circuit modifications, i.e. 190 kV; 300 kV could be obtained if necessary. This test had to be delayed until the second half of July because two series of adapting parts had to be built in order to equip the Pirelli cable with the standard LEP (SL) H.V. oil insulated connectors. The converted assembly is shown in fig. 3.

The test was very successful, the cable being kept under 190 kV D.C. during three days, with an apparent leakage current around 20 to 30 pA. It is not clear which fraction of this current was real; most probably came from leakage outside the cable.

5. Low temperature electrical tests

The setup was modified using a Dewar containing about 25 m of cable tightly wound in a small coil of 40 cm in diameter.

The tests were run in liquid nitrogen during six days at the same constant voltage of 190 kV D.C., again with excellent results. The leakage current was very small, around 20 to 30 pA, as in the previous test on a much shorter length at room temperature, again suggesting that most of it was not resulting from a leakage along the cable.

Short low level current spikes were present in both tests throughout the recording. With good probability these spikes may be attributed to the electrically noisy environment of the test hall.

6. Remarks

The combined cryogenic and H.V. tests were carried out in full at CERN also because the supplier did not have immediately available low temperature and D.C. high voltage facilities, industrial H.V. cables being most frequently tested with A.C.

This cable was the second one manufactured by Pirelli. A first prototype in polyethylene showed some brittleness at low temperature. At this point we may note that the cryogenic performance of an insulator should not be judged by its sudden immersion in liquid nitrogen. During the quenching the outer layer contracts very rapidly while the low thermal conductivity of the material allows the inner core to reach the thermal balance only slowly. The combination of the thermal contraction with the small elasticity at low temperature may well bring the outer skin beyond the point of rupture, whereas no high stresses are present if the cooling is slow and the temperature fairly uniform in the whole sample. Because of the difference in thermal coefficients the plastics will wrap the wire tightly at low temperature.

7. Conclusions

The EPR H.V. prototype cable supplied by Pirelli has performed according to our expectations during the preliminary tests made between July and September 1999. The testing could have been more complete if we had not been working under strict boundary conditions concerning manpower, money and time. It would have been most interesting to extend the tests both in time and in voltage in order to secure information about the possible operating limit. Our impression, confirmed during discussions in Milan with Dr. G.M. Lanfranconi of Pirelli, is that the cable is conservatively designed with a sufficient margin for an extended period of operation.

As for the purpose originally foreseen for the cable, i.e. to establish a mechanically tight electrical connection between a lab at ambient temperature and the inside of a cryogenic vessel, we do not see any objection to its feasibility. Building a "stuffing box" to seal the passage of the cable all around has been considered outside the scope of the tests, essentially because the available resources did not allow its construction in a reasonable time. But such an item would be a necessary facility for extending the tests as well as for finalizing the design.

8. Acknowledgements

We wish to acknowledge here the help given by the staff of the LHC/ECR Cryogenic Lab and of the SL/MS High Voltage Lab. P. Hebras took care of the setup in the H.V. area while C.Nuttall and Mme C.Bertoux (TIS/CFM) provided the means to check that the evaporating liquid nitrogen did not adversely affect the atmosphere in the test cabin.

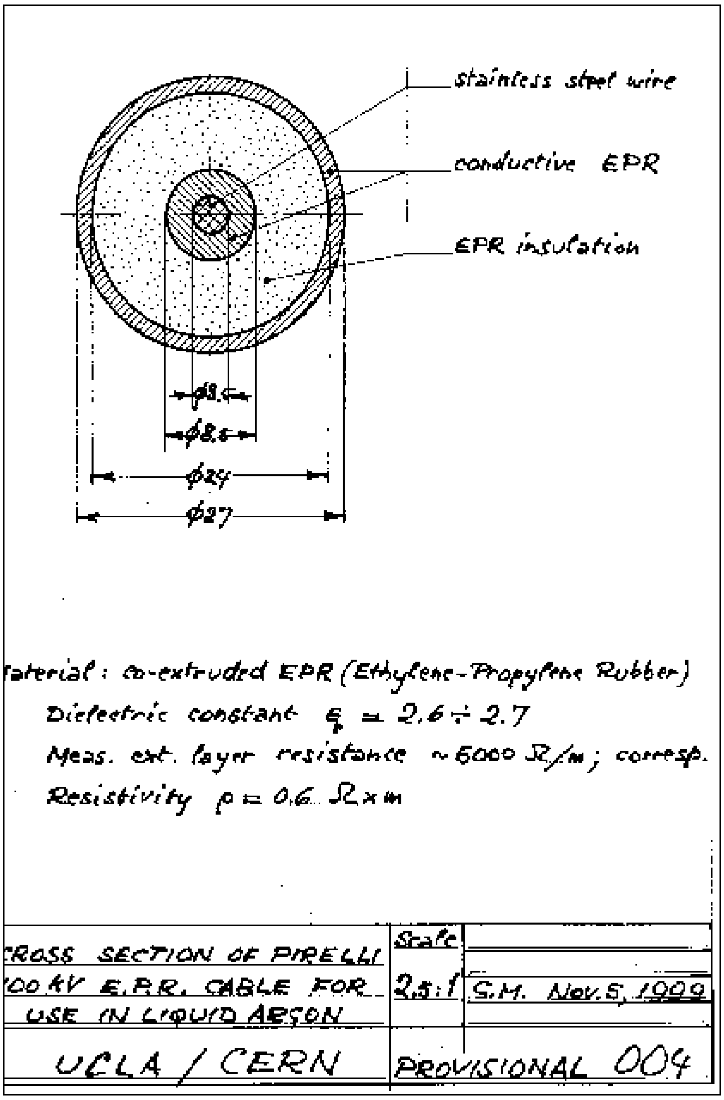

Figure 1. Cross section of Pirelli cable

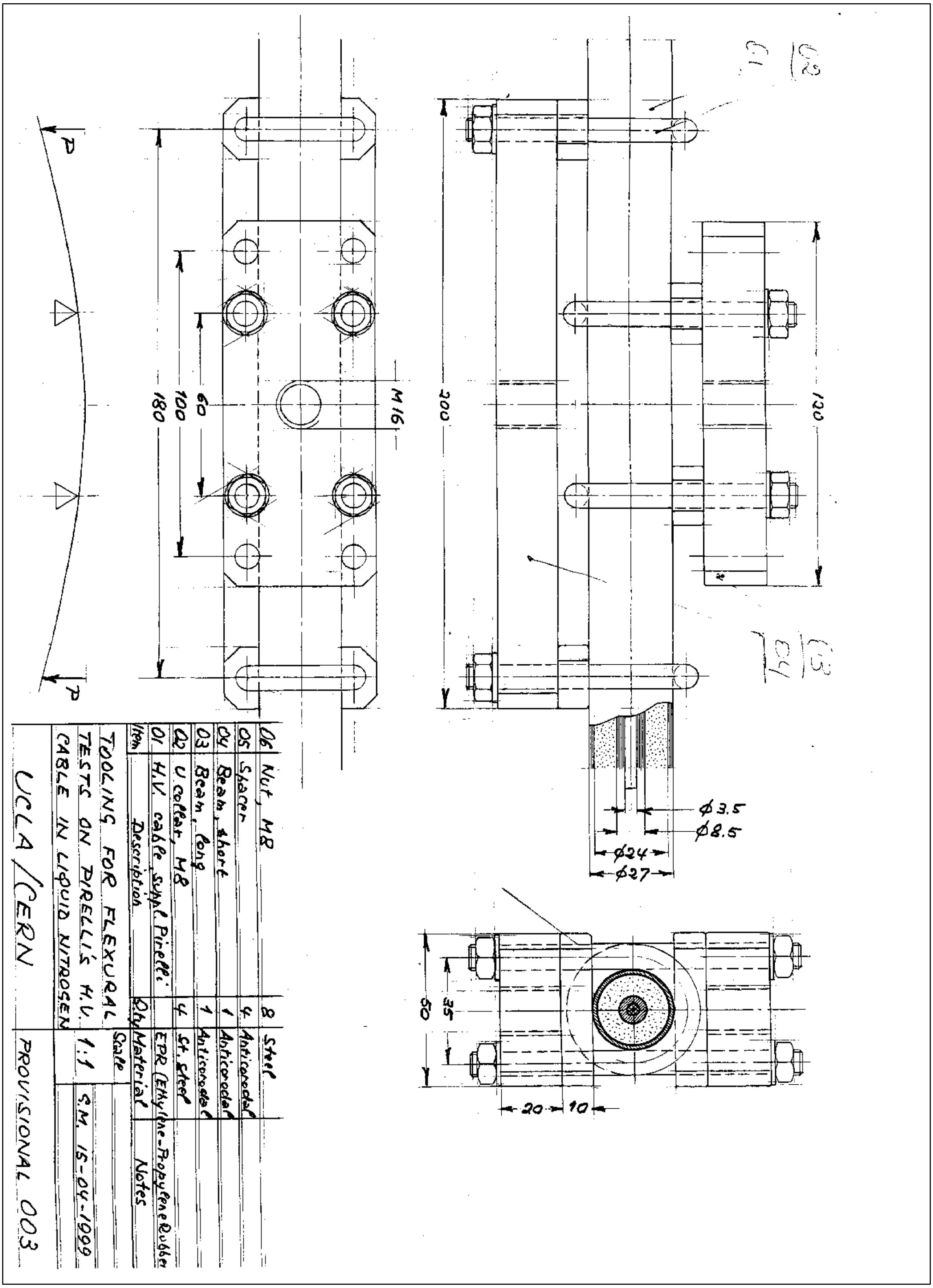

Figure 2. Equipment for flexion test.

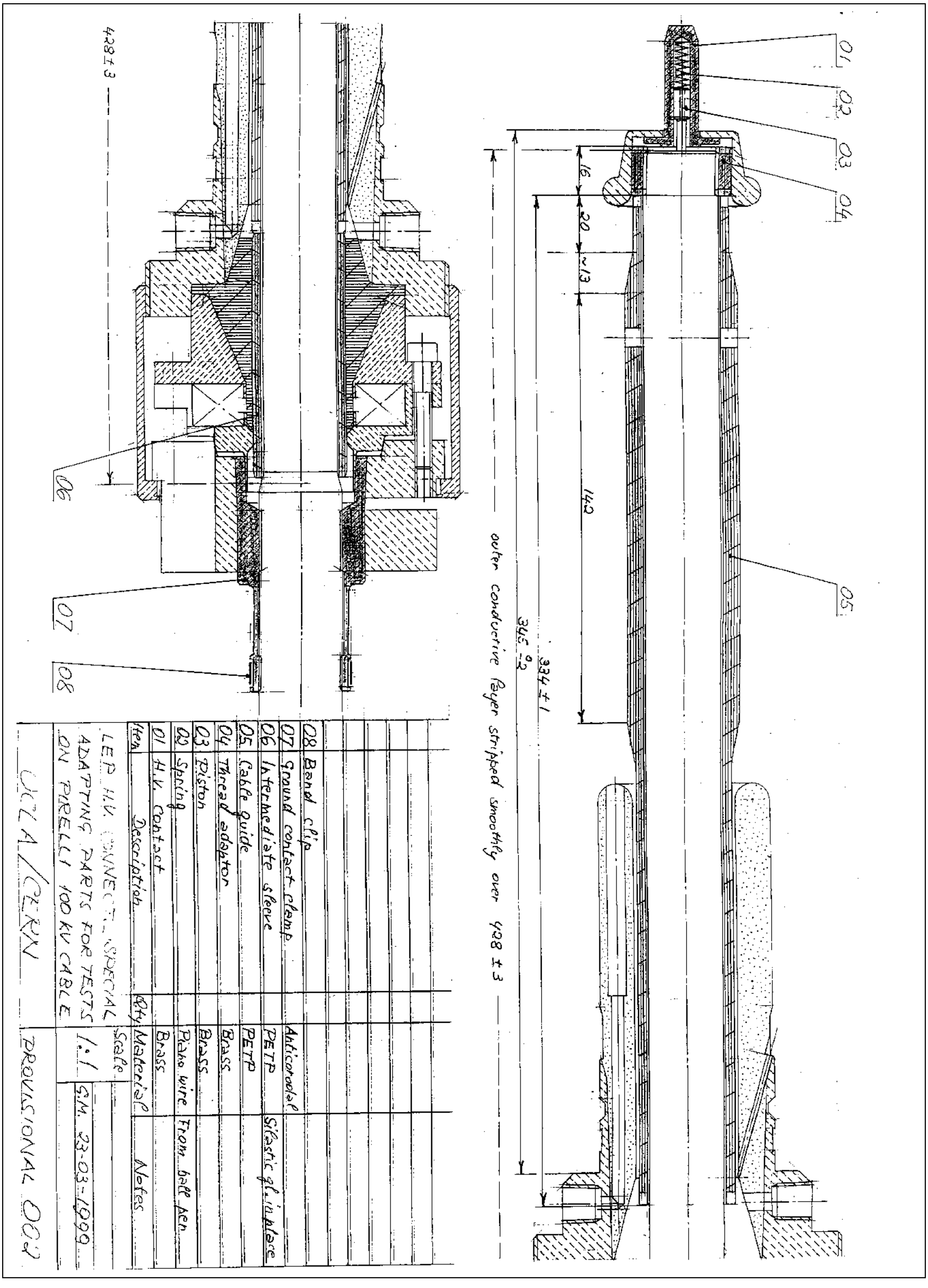

Figure 3. Converted H.V. connector (adapted from existing LEP design).