Failure mechanism and consolidation of the compensation bellows of the LHC cryogenic distribution line

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Introduction

The Cryogenic Distribution Line (QRL) takes part of the LHC cryogenic cooling system at CERN. It contains four/five helium pipelines so-called headers. The layout of standard cell is presented in Figure 1.

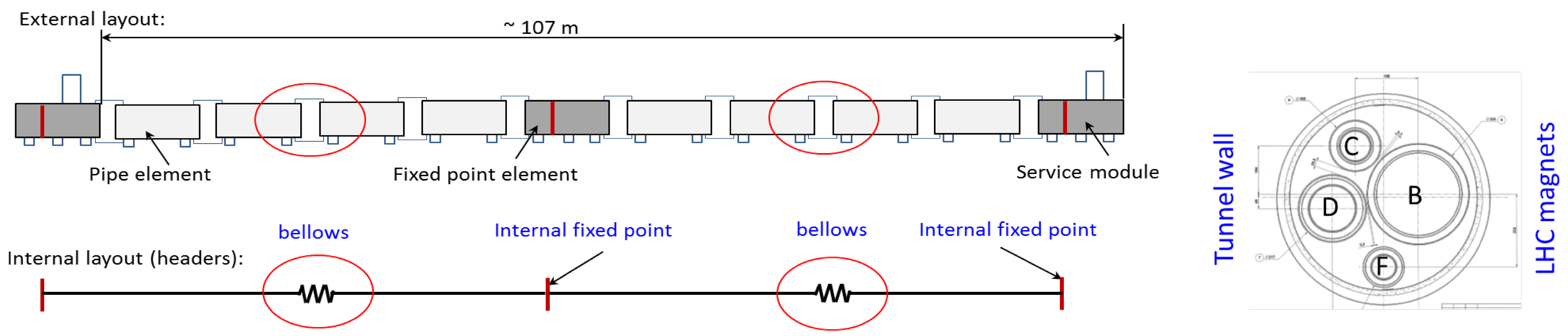

Fig. 1. The QRL standard cell layout.

The first sign of tightness problem occurred already during the 2010/2011 end of year technical shut down when one leak on the QRL header C was declared during partial warm up of the system to about 80 K. Helium leak detection by means of time-of-flight over 400 m vacuum subsector identified leak zone where the bellows are installed to compensate thermal contractions of the line at each ~53.5 m.

The X-rays of the suspected interconnection confirmed visually deformations on header C bellow. The X-ray and photo of later removed bellow are presented in Fig. 2a and 2b.

After complete warm up of the machine for long shut down period the performed X-ray campaign confirmed damage and repair necessity on 16 compensation bellows – see Fig. 3.

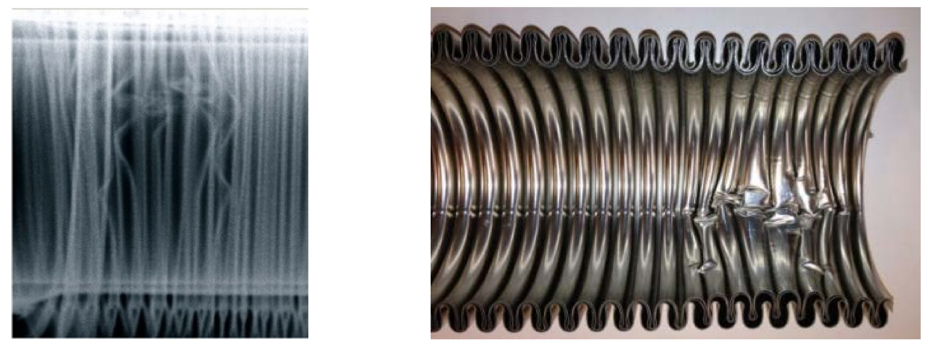

Fig. 2. (a) X-ray of first leaky bellow;
(b) photo of the first leaky extracted bellow.

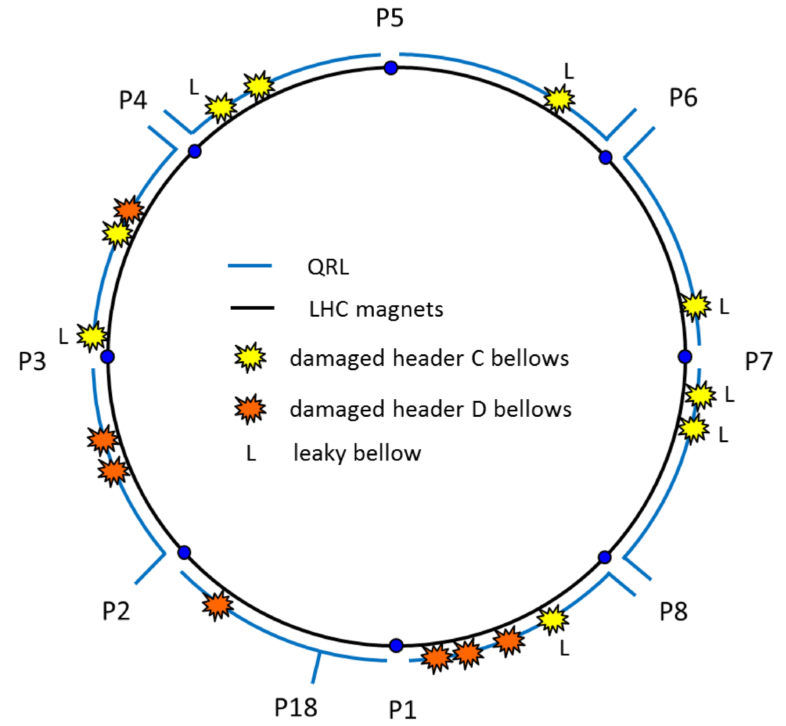

Fig. 3. Repartition of damaged compensators

Compensation bellow design

The bellows chosen for the QRL installation are working with external helium pressure. Because of mechanical requirements the intermediate bellow part was fabricated as multiply assembly welded to the flanges on both extremities to provide lower stiffness and helium tightness – see Fig. 4.

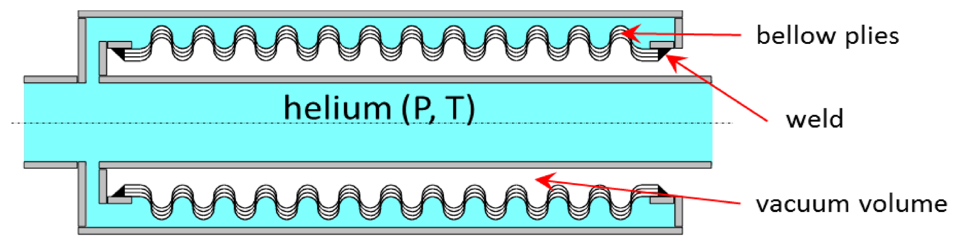

Fig. 4. The simplified bellow design.

Failure mechanism explanation

After the long shut-down warm-up the situation required full investigation and understanding the problem origin. The detailed analysis of the X-rays confirmed clear damage of the bellow plies – see Fig. 5.

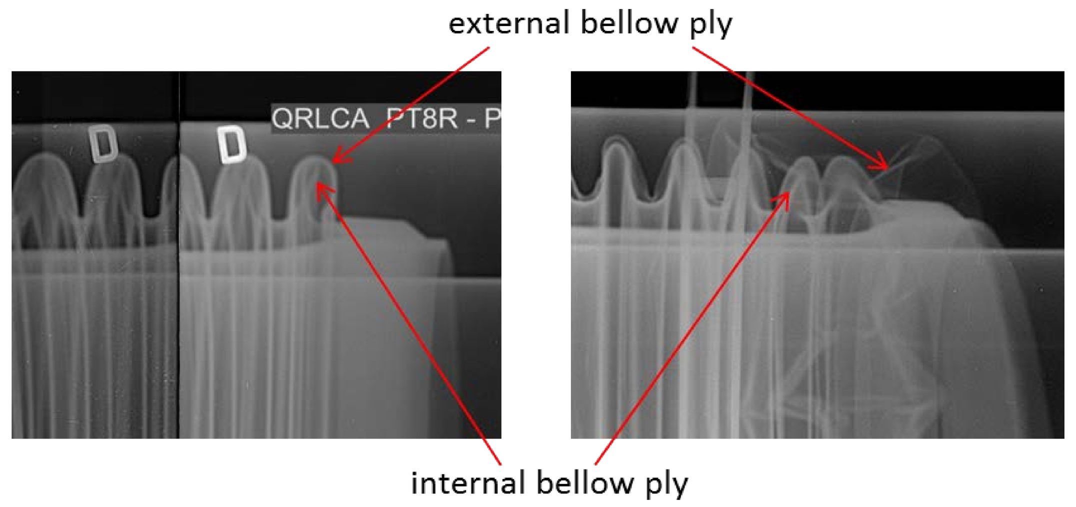

Fig. 5. X-rays of damaged compensator plies.

This finding leaded to presume that during three years of operation some bellows faced with the helium tightness problem into the inter-ply volumes. The metallurgical analysis confirmed existence of a crack on the double weld between the plies extremity and the flange – see Fig. 6.

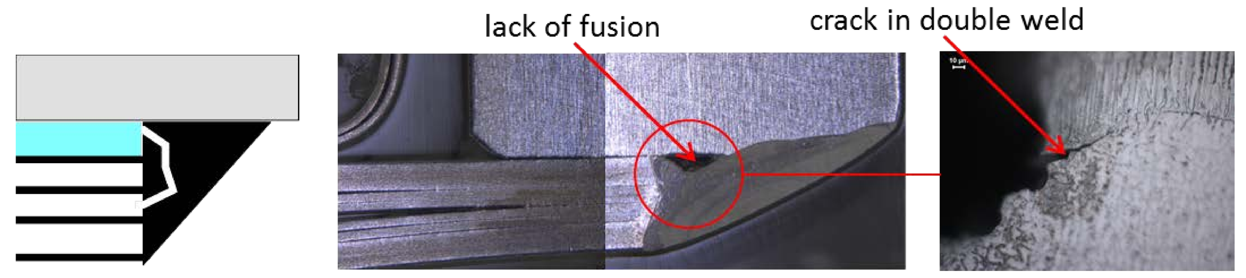

Fig. 6. Crack in double weld allowing helium passing in between the plies.

During warm up the supercritical helium trapped in-between the plies did not have enough time to escape via the micro leaks. The increasing inter-ply pressure leaded firstly to bellow deformation and secondly to creation of traversing leak from helium to the vacuum volume. Visual representation of the damage sequence is presented in Fig. 7. The effect of the helium discharge from the inter-plies volume to the vacuum was visible on vacuum pressure monitoring and is shown on the graph in Fig. 7.

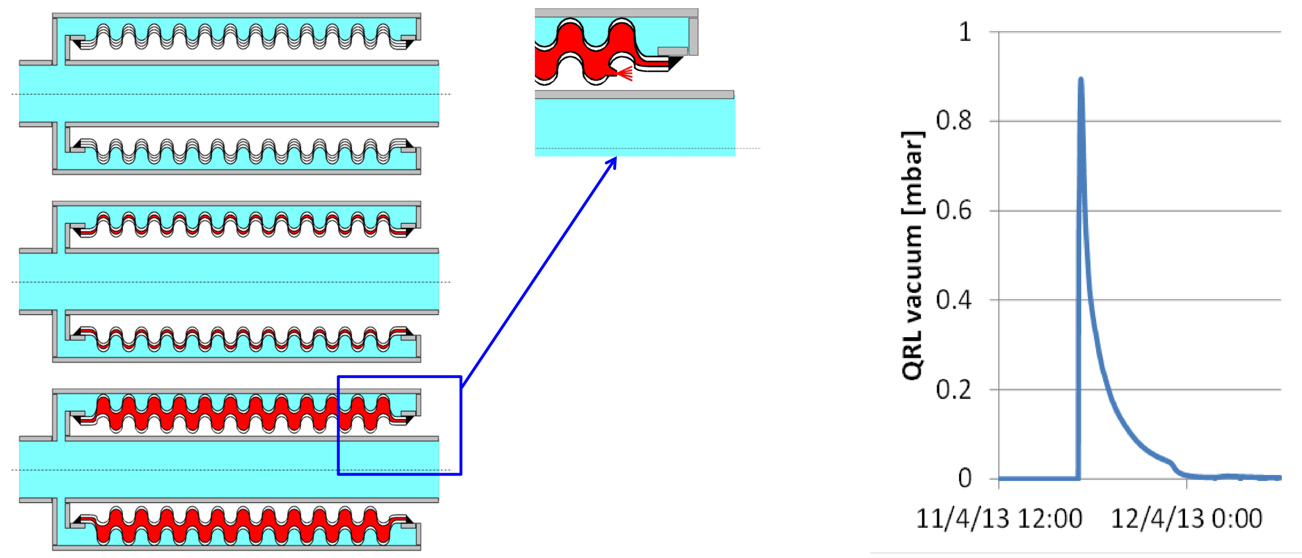

Fig. 7. The bellows damage sequence with the insulation vacuum pressure evolution .

Repairs and new spare bellows design

The repairs required the order of additional spares. In parallel with existing old spares validation, CERN together with original bellows supplier applied improvements in the compensator design:

- The new spares have modified flange shape and weld between the plies extremity and the flange – see Fig. 8. The new design allows welding of the 4 plies in one passage.
- The other modification is to keep only one ply tight (on the helium side) and all other plies are perforated to create ventilation holes.

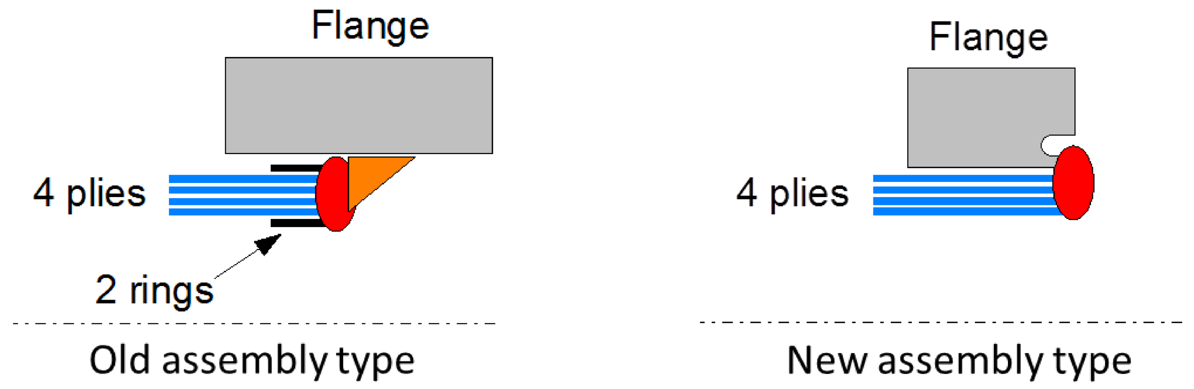

Fig. 8. The modified assembly procedure for new type of spare bellows.

The total repair, including new spares, cost about 1 MCHF. Although the guarantee period of the QRL distribution line was over, Air Liquide – the QRL supplier, has recognized the problem (insufficient evaluation of the risk with dead volume and weld defects of their supplier) and contributed substantially to this repair cost.

Conclusions

After the first LHC operation run, eight year after installation completion of the QRL distribution line, sixteen thermal compensators were found damaged following the LHC warm-up and have to be repaired during the first long shut-down. The failure mode has been identified and is due to the over-pressurization of the non-controlled inter-ply volumes in case of link of these volumes with the process fluid via leaks. The encountered failures were linked directly with fabrication problems. As basic rule, the design of non-controlled volumes is not recommended for cryogenic applications. Consequently, the use of vented-plies is advised for cryogenic compensators. However, if for specific applications several plies need to be tight (e.g. if the compensator need to withstand individually high internal and external pressure), the bellow should be validated for tightness by means of the boombing test.

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