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Thermal Cycle Test for Invar Pipe with Fixed Ends and Many Welds

By R. J. Walker, G.W. Foster, and Tom Moreland *

Introduction

This report discusses some work which was done to help insure the wisdom of using an invar (36 % Ni steel) cold tube as the vacuum containment for a transmission line type conductor for magnetizing warm iron for a very large hadron collider. The advantages of invar are that it has a very low coefficient of thermal expansion. The expansion is so low that the transmission line can be built without the use of bellows or other flexible sections, which would result in lower cost and increased reliability.

The goal is to test whether the invar pipe can undergo many thermal cycles from 300 K to saturated liquid nitrogen temperature while the ends of the pipe are held fixed. A secondary goal is determine the cryogenic reliability of a large sample of invar welds.

Ideally, the strain induced in the invar during a cool down is independent of the total length of the pipe. In a world with errors, such as bending of supports, one gets a more accurate test by using a long pipe. The use of a long pipe reduces the importance of end effects, where the undesirable bending occurs.

Description of the test assemblies

50 random lengths approximately 3 m long of 0.038 m diameter by 0.00124 m wall invar drawn tubing were obtained from Sanborn Tube near Milwaukee Wi. Four test assemblies were made up in the Fermilab central shop with an automatic orbital welder. See figure 1. Each of the test assemblies was made of 33 sections of the invar stock 0.0762 m long before welding. This procedure resulted in 32 automatic welds in each of the four test assemblies. Each of the four test assemblies had a 0.305 m length of the invar stock hand heliarc welded to each end to facilitate installing in the long pipe and the leak test fixture. This ultimately increased the number of tested welds to 128 of the orbital type and 8 hand welds.

Initial leak testing

The next step was to fabricate a fixture for leak testing which enclosed a test assembly described above inside an aluminum tube 2.522 m long with 0.00158 m wall thickness. A KF40 fitting was provided in the center of the tube to attach it to Du Pont model 120 SSA helium leak detector. The sensitivity of the leak detector was typically 10-10 std cc/sec. All four test assemblies passed the warm pretest at the maximum sensitivity of the leak detector.

Description of the test site and the holding fixtures

Associated with the Fermilab Central Helium Liquefier is a cryogenic piping yard which lies to the east of the main CHL building. In the eastern most portion of this yard is a line of liquid nitrogen storage dewars which extend from south to north. See figures 2 and 3. The piers used to support these dewars were used to anchor the fixtures which held the ends of the long invar pipe fixed, or at least as fixed as we could. The piers which support these dewars extend below grade level a distance of 1.67 m and ending in a buried pad 1.82 m wide by 3.65 m long. The above data is for the northern most pier supporting a 42000 liter dewar. The southern most pier is somewhat larger and supports a 190,000 liter dewar. There are two piers supporting each of these two dewars

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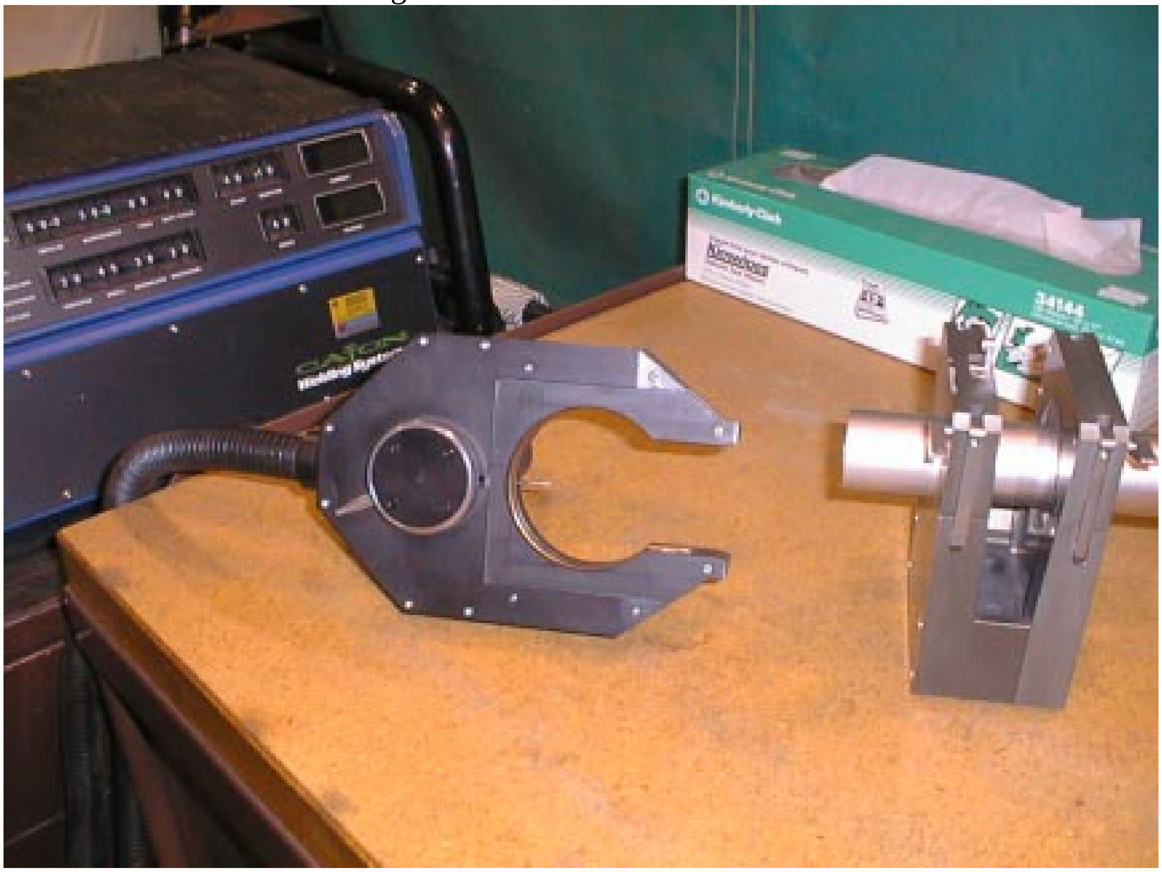
Figure 1. Automatic Welder



The holding force is extended from the piers by 6061-T6 aluminum channels, 0.3048 m wide with a 0.127 m wide web of thickness 0.0157 m. See figure 4. The channels extend 0.482 m beyond the end of the pier to avoid various obstacles. The channel at each end is equipped four ¾-16 jacking bolts (US standard bolts, inches) which enable adjusting the initial tension to a desired value. The jacking bolts were also used for a Young's modulus measurement of the invar warm and cold. The bending of these beams during the thermal cycles is a source of error and the magnitude will be evaluated later in this note.

The long invar pipe had two of the multi-weld test assemblies on each end with the center portion made up of the random lengths of the 0.038 m diameter invar tube. After welding, the total length of invar was insulated with urethane foam insulation covered with heavy duty aluminum foil. The insulation was necessary to be able to bring the whole tube length to 77.3 K.

Load cell calibration

The bending of the beam in the overhanging portion was calibrated against a load cell with a 907. Kg wt. span. The load cell was manufactured by Tri/Coastal Industries, Inc. and was model number 26410-202. Figure 4 shows the mounting of the load cell. The long invar pipe to be stressed was mounted similarly to the way the load cell was mounted except that the north most beam was moved to the northern most pier, approximately 145 m north. Resulting in a total invar length of 146.5 m. Figure 5 shows the response of the beam to a load cell force, and the bending is measured at the end of the beam. The maximum bend at the end of the support at a load of 907 kg wt. was 0.0010 m.

Throughout the test, the force was deduced from the bending of the southern most beam.

Figure 2. Photo of the Line Near the North End, Looking South

Figure 3. Photo of the Line Near the South End, Looking South

Integrated thermal expansion and Young's modulus measurement

The change in the overall length of the invar tube was measured at 300.2 K and at 77.3 K. There was no tension in the tube and the end was free to move. The number is $\Delta L/L = 3.185 * 10^{-4}$. By comparison, Van Sciver 1 gives $4.8 * 10^{-4}$. We believe that the difference is due to large variations in invar expansion coefficient for small changes in composition.

The Young's modulus measurements were made by tightening the jacking screws to bring the force to a desired value. After tightening screws, the length change was measured by observing the distance to the jacking block from a point fixed relative to the pier. The warm measurements are shown in figure 3 and the 77.3 K measurements are shown in figure 4. A linear fit to the data is shown in the plots and this slope is used to calculate Young's modulus from the cross sectional areas. Both of these curves showed some dropping off of the force

below the linear behavior at the larger stretch values. This is not understood. For the modulus numbers, the average slope shown in the linear fit was used.
At 9 C, Young's modulus calculates to 1.57e+5 MPa, and at 77.3 K the value is 1.60e+5 Mpa. A Carpenter Steel document2 gives (70F?) 1.48e+5 MPa cold rolled and 1.41e+5 MPa annealed. The difference is most likely due to the degree of cold working in the drawn tubes used in the test (higher).

Thermal Cycles

At the start of the thermal cycles the force was reduced to 136 kg wt. at a chosen value of 10 C. This is enough force to compensate for the bending of the support beams and keep the maximum force at a level corresponding to the value the invar would attain in a truly fixed end operation. A thermocouple at the north end of the pipe, away from the source of heating and cooling was used to decide if the cold or warm end of a cycle was attained. A PC was set up to switch the supply valves to warm gas or liquid nitrogen when the temperature reached a minimum or maximum. It turns out cycle tests. Note that each force cycle is accompanied by a change in fluid from saturated liquid nitrogen (high stress point) to 10 C gas (low stress point). The 24 hour variation in the envelope of force variations follows the outside temperature causing the dewars to stretch and move the supports slightly thereby stretching the invar tube. Note that the force never went negative during the test.

Final leak check

After 1005 cycles of the type shown in figure 8, the four test assemblies were removed from the line and the leak check that was performed before the cycles was repeated. No leaks were observed. From this it was concluded that the invar and the welds are acceptable for VLHC service.

In order to study the drifts, if any, of the forces developed at the maximum points, minimum points, and the swing from peak to valley, the peaks and valleys were identified and plotted over the course of the thermal cycles. The result is shown in figure 9. It appears that the main trend in peaks, valleys, and swing is quite stable, and this implies that the invar is not undergoing any sort of disintegration.

Figure 4 Load Cell

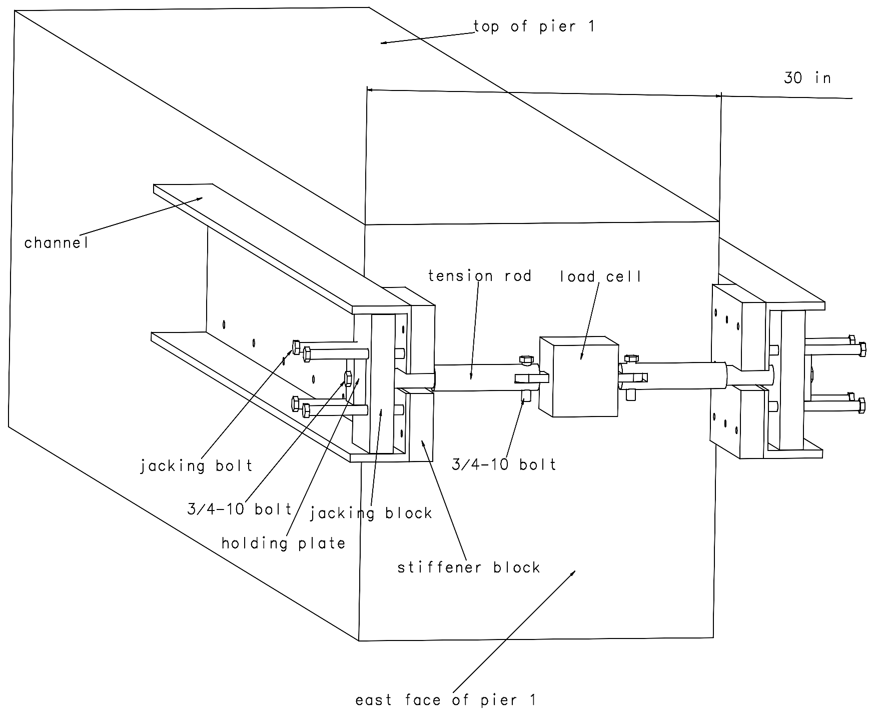


Figure 5. Beam bending response

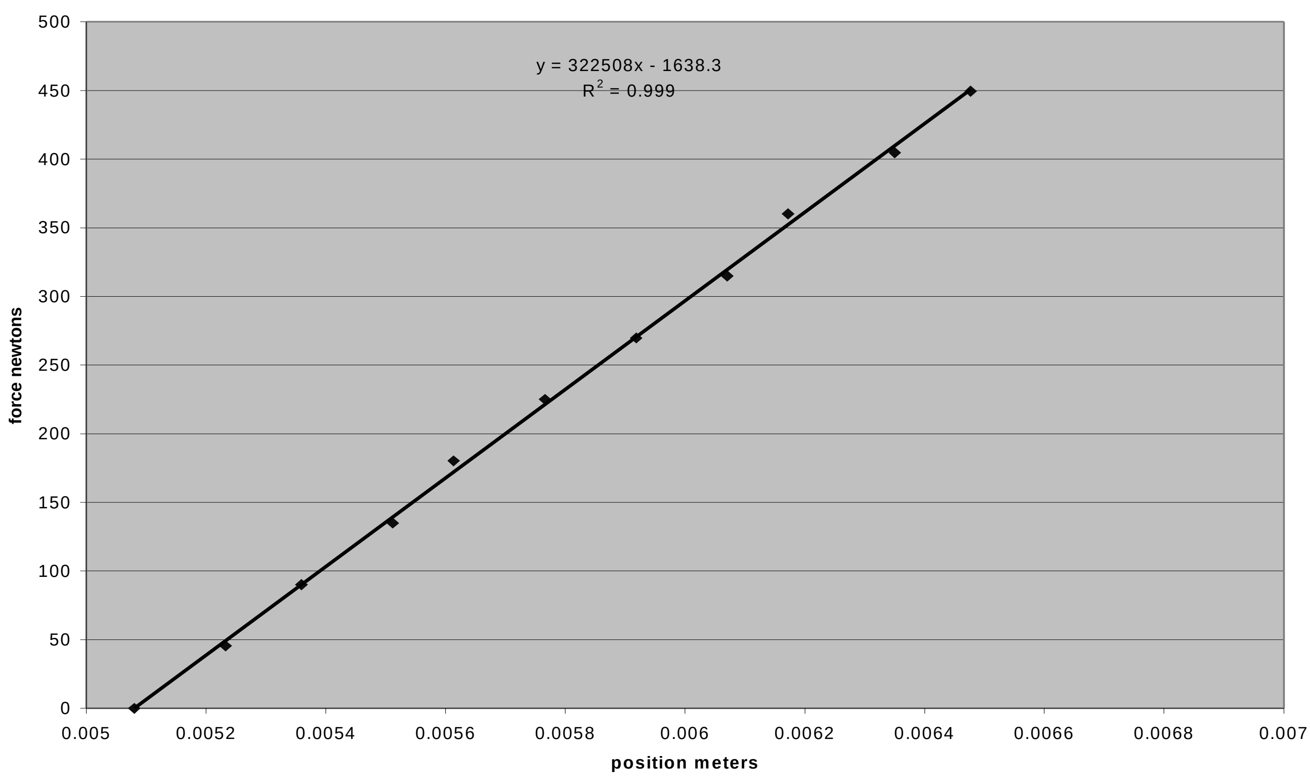


Figure 6 Force vs Stretch at 9 C

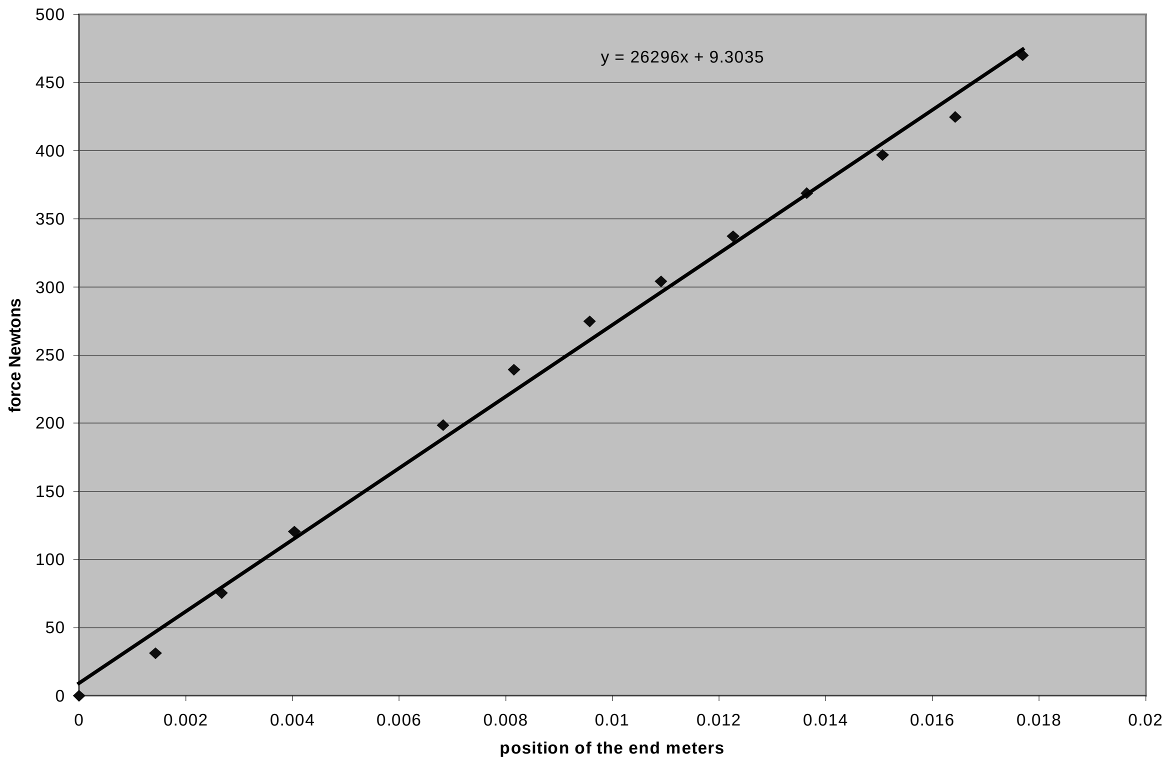


Figure. 7 Force vs Stretch at 77.3 K

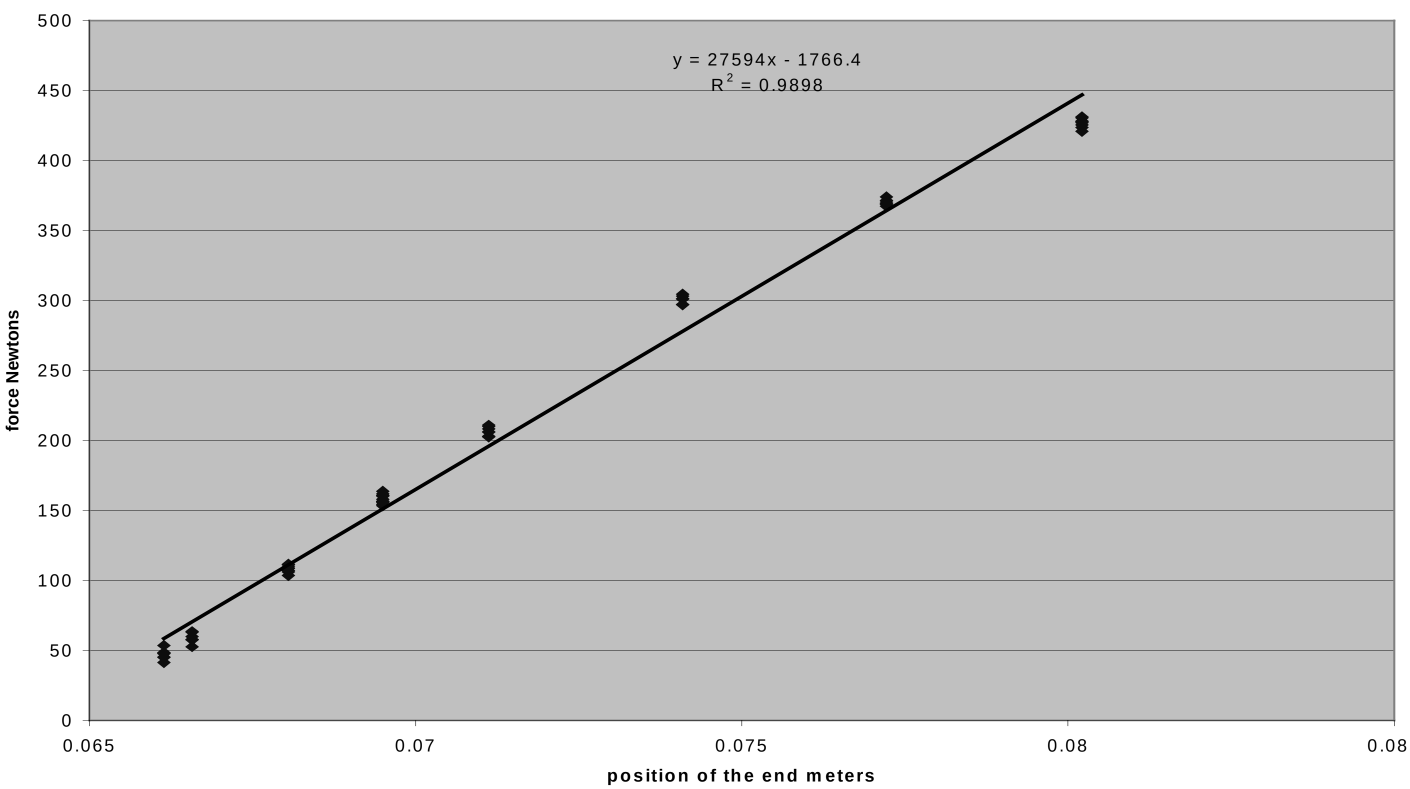


Figure 8. Typical Plot of Force Cycles vs Elapsed Time During Thermal Cycles

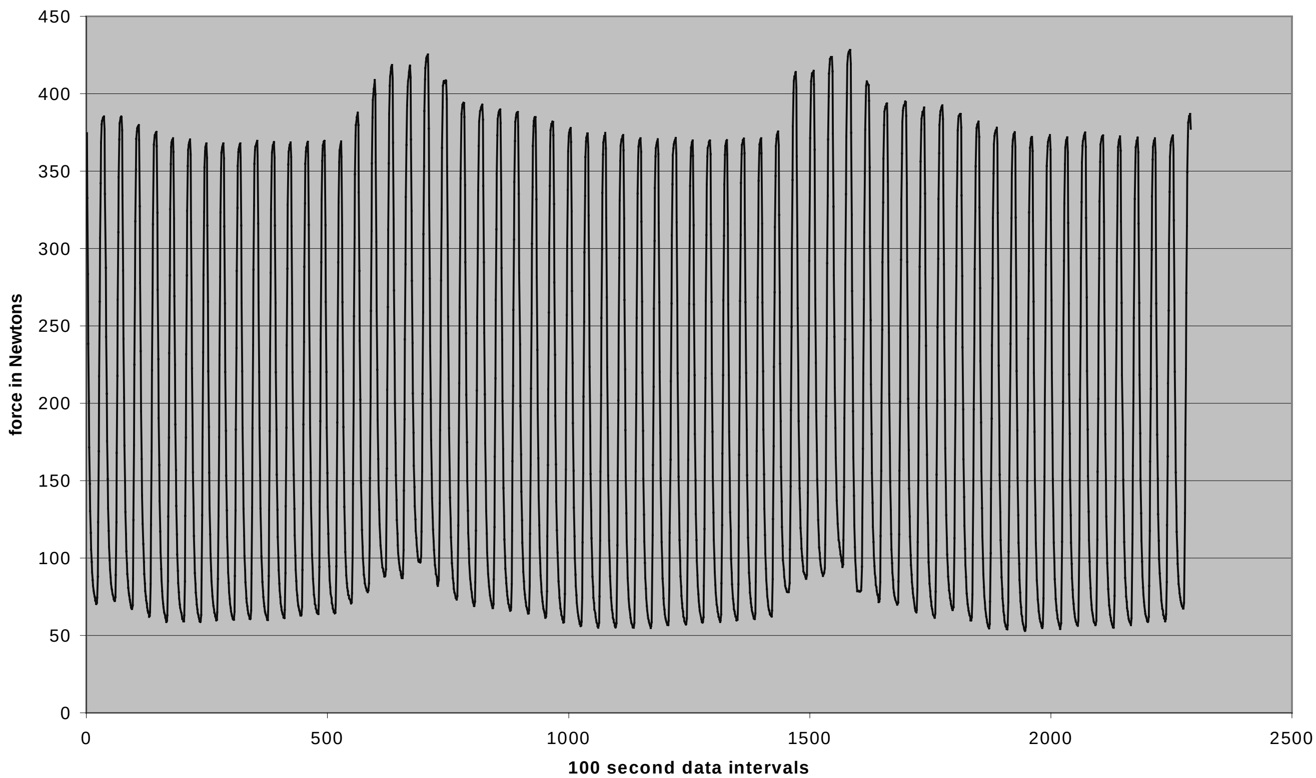
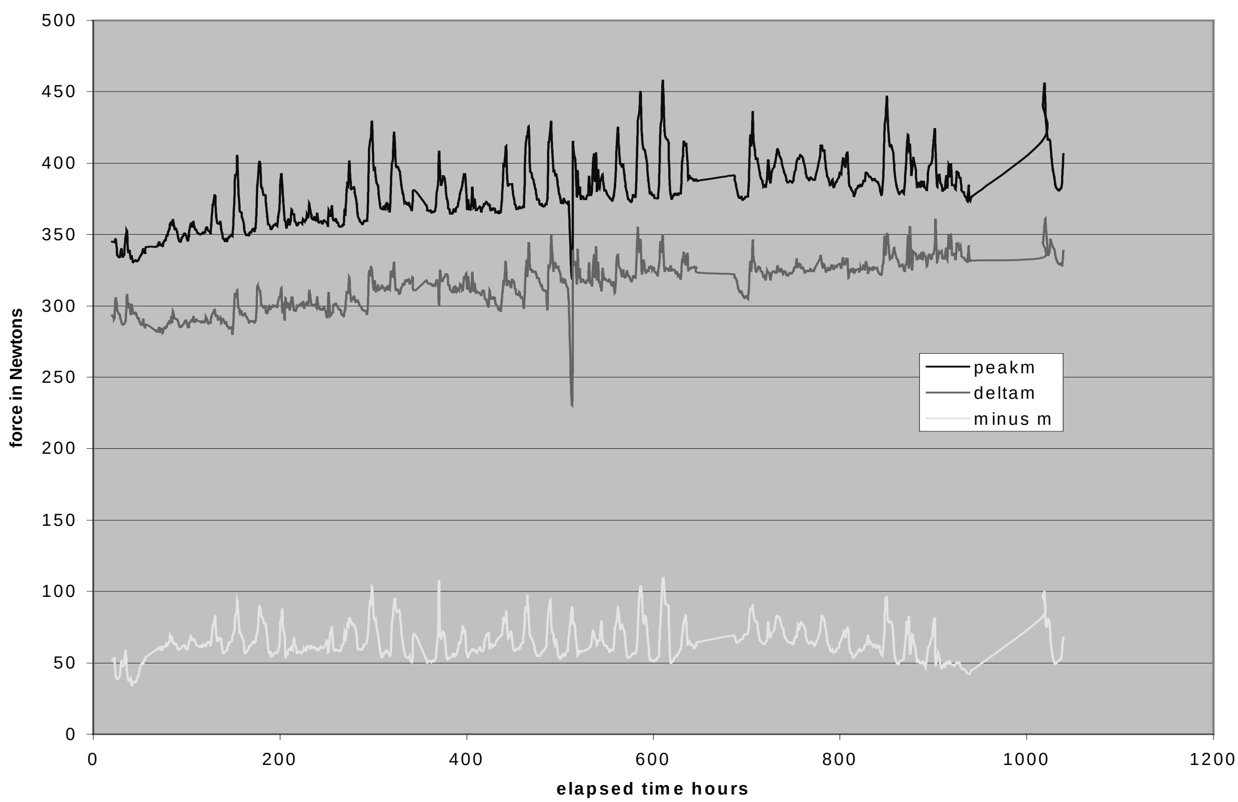


Figure 9. Overall Trend of Peaks, Valleys, and Delta



Conclusions

We have concluded that there has been no adverse change in the invar during the 1005 thermal cycles with 128 welds of the type expected to be used in the VLHC. After the cycles, all the test welds were tested with no observed helium leaks. It is to be noted that these tests gave no information on what might happen in the temperature range from 77.3K to <5K.

References:

1. W. Van Sciver, Helium Cryogenics, Plenum Press, New York, 1986.
2. Carpenter Technology Corporation, Melrose Park, IL, 1997