TS-SSC 91-113
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Comparison of Prestress in DC0304-DC0306

This note will compare and summarize the coil and prestress data for magnets DC0304, DC0305 and DC0306.

The inner cable used in DC0306 was manufactured by Furakawa Electric Co., LTD whereas the cable used in the coils of DC0304 and DC0305 was manufactured by New England Electric. The outer cable used in DC0304 and DC0306 was also manufactured by New England Electric while the cable used in DC0305 was from LBL[1]. The following table gives the characteristics of the inner and outer coils used in these magnets.

Coil Number	Magnet	Ave Azim. Size*	M.O.E.**
17M-1014R	DC0304	4.0±2.4	2.2±0.4
17M-1013	DC0304	4.1±1.2	2.3±0.4
17M-1006R	DC0305	5.0±1.3	2.3±0.2
17M-1007R†	DC0305	3.5±1.4	2.3±0.4
17M-1011R	DC0305	1.9±1.2	1.8±0.9
17M-1015	DC0306	10.7±1.1	2.2±0.1
17M-1016	DC0306	10.4±1.2	2.4±0.2
17M-2007	DC0304	2.9±0.8	2.3±0.2
17M-2005R	DC0304	1.6±0.8	2.4±0.4
17M-2014R	DC0305	3.3±1.1	1.8±0.2
17M-2015	DC0305	2.2±1.2	2.1±0.5
17M-2008R	DC0306	3.2±1.1	2.4±1.3
17M-2006R	DC0306	3.0±0.8	2.9±1.0

* Average Azimuthal Size at 12 kpsi relative to the master gage block.

** Average Modulus of Elasticity $*10^{-6}$, measured between 8kpsi and 12kpsi. The error is the standard deviation of the measurements.

† Coil used in first keying attempt.

As can be seen from the above table, the two coils made from Furakawa cable and used in DC0306 were significantly larger than

the inner coils used in the previous magnets even though there was no change in the coil winding and curing process. The thickness of the Furakawa cable was approximately 0.4 mils oversize and this would account for the 7 mil oversize coils[2]. The modulus of elasticity was the same as that of the cable used in the other magnets.

The desired inner coil prestress of a keyed magnet is between 8 and 12 kpsi. In order to achieve this, a shim is placed on the poles of the inner and outer coils to compensate for variations in coil size[3]. This shim consists of adhesive backed kapton tape which makes a precise determination of the actual thickness after installation difficult[4]. Typically, when 10 mils of kapton are called for, the measured thickness of the kapton will be 7 mils, while the measured thickness of the kapton plus adhesive will be 10.6 mils. The following table shows the thickness of the shim called for in DC0304-DC0306[5], along with the maximum stresses developed during keying and the final stresses in the keyed coil after removal from the press, as determined by averaging over the four inner and four outer strain gages.

Magnet	Inner Shim	Max Stress Lead End Inner Coil	Max Stress ReturnEnd Inner Coil	Final Stress Lead End Inner Coil	Final Stress Return End Inner Coil
304	17 mils	18700 psi	18400 psi	13100 psi	14800 psi
305	17 mils	10400 psi	10700 psi	7900 psi	
306	10 mils	15200 psi	20700 psi	9800 psi	14400 psi
	Outer Shim	Outer Coil	Outer Coil	Outer Coil	Outer Coil
304	10 mils	22700 psi	20200 psi	9600 psi	8800 psi
305	10 mils	15800 psi	16800 psi	8900 psi	
306	10 mils	20000 psi	20200 psi	8400 psi	10250 psi

The complete prestress history for each gage individually and for the average of the inner and outer gages is shown in figures 1 through 18 for these magnets. A computer error caused the press data to be lost for DC0305, however it appears that the maximum press pump pressure was 7000 psi[6] leading to a stress of about 11 kpsi. (The DC0305 figures were generated assuming the standard keying procedure.) From table 2 and the figures one sees that magnets DC0304 and DC0306 developed approximately the same very high stresses, within the errors of the gages, whereas DC0305 seemed to develop significantly less prestress (note that the inner coil shim has been changed for DC0306 to compensate for the larger coil size). It should be pointed out that DC0304 was keyed using a 32 mil shim in the collaring press while DC0305 and DC0306 were

collared with modified shimming to reduce overstressing the ends. Hence one might have expected DC0305 and DC0306 to be more similar. (Note: DC0305 was keyed at two different times; both attempts ended when an electrical short developed while the coil was in the press. The data presented in the figures is from the second keying attempt.) Figure 19 shows the measured coil stress versus the vertical press hydraulic system pressure for these magnets[7]. It is obvious that the apparent stress in DC0305 is increasing at a slower rate than that of the other two magnets or than the expected rate if the full press load were balanced by the coils. The reason for this behavior is not known.

A result of reducing the shim in the collaring press during the keying of magnets DC0305 and DC0306 was that the keys in DC0306 were not fully inserted with 2 kpsi horizontal force and extended up to 75 mils out of their slots. They were fully inserted (after the coil was removed from the keying press) with rubber mallets. The maximum extension of the keys in DC0305 was 79 mils, however the keys on the quadrants 1/4 side of the coil were significantly farther out than those on the quadrants 2/3 side. The fact that the keys were not significantly farther out than on DC0306 may have been due to the lubricant used on the keys during the keying of this magnet and the lower stress developed within the collared assembly. The reason for the asymmetry in key insertion is not known. The keys were fully inserted at the lead end gage pack of DC0305 but not at the return end gage pack, hence the final stress at the the return end gage pack is not known. No attempt was made to further insert them because a short developed in the lower inner coil.

The high prestresses developed by DC0304 and DC0306 during keying was followed by a large prestress loss upon removal of the collared coils from the press. The outer coils lost over 10 kpsi and the inner coils 4 to 6 kpsi. There was some additional prestress loss ($\leq$1500 kpsi per inner or outer quandrant) over the three weeks until the cryostated magnet was shipped to the test facility.

One additional point that should be made is that the lead end gage pack is positioned at the smallest summed azimuthal size of the inner coils while the return end gage pack is located at the maximum of the summed coil sizes. Typically the difference in summed azimuthal size between these extremes is 16 mils, leading to the expectation that the stress difference between the measurements of these packs should be on the order of 4 kpsi. Only DC0306 shows this large a difference; DC0304 and DC0305 show a difference on the order of 1 kpsi.

In conclusion, magnets DC0304 and DC0306 exhibited very high prestresses during the keying procedure followed by large spring back losses. The prestresses on the inner coils may be approaching the limit of the kapton insulation even in the case of DC0306 where the collaring press shimming had been modified to reduce the large stresses near the ends (which had resulted in failures in DC0302 and DC0303). This is especially true in light of the fact that the stress appears to be concentrated at the inside edge of the inner cable at the mid-plane[8]. It is unclear why the prestress in DC0305 was so low up to the time it failed do to a turn to turn short. There appears to be $\leq$ 1500 psi prestress loss over the 3 weeks between the time the cold mass is completed and the cryostated.magnet is shipped to test.

1 B. Jensen, private communication
2. M. Wake, TS-SSC 91-061, 3/29/91
3 J. Strait, TS-SSC 90-005, 4/4/91
4. M. Winters, TS-SSC 91-106
5. J. Strait, TS-SSC 90-106, TS-SSC 91-018, TS-SSC 91-027
6. D. Smith, private communication
7. After J. Strait, TS-SSC 91-004, 1/14/91
8. M. Wake, TS-SSC 91-046

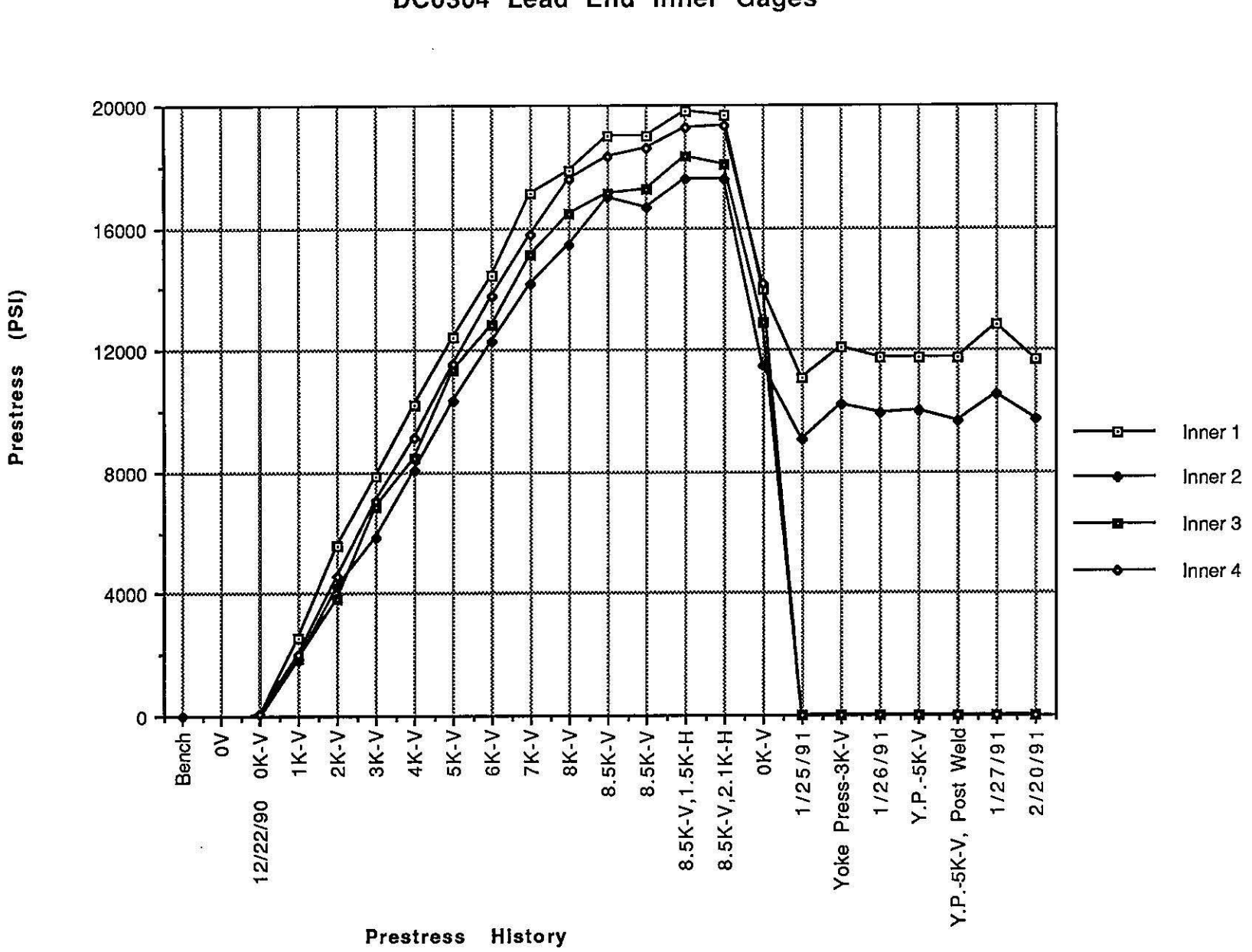

DC0304 Lead End Inner Gages
Prestress (PSI)
20000
16000
12000
8000
4000
0
Bench
0V
0K-V
1K-V
2K-V
3K-V
4K-V
5K-V
6K-V
7K-V
8K-V
8.5K-V
8.5K-V
8.5K-V,1.5K-H
8.5K-V,2.1K-H
0K-V
1/25/91
Yoke Press-3K-V
1/26/91
Y.P.-5K-V
Y.P.-5K-V, Post Weld
1/27/91
2/20/91
12/22/90
Prestress History
Inner 1
Inner 2
Inner 3
Inner 4

Fig 1

DC0304 Lead End Outer Gages

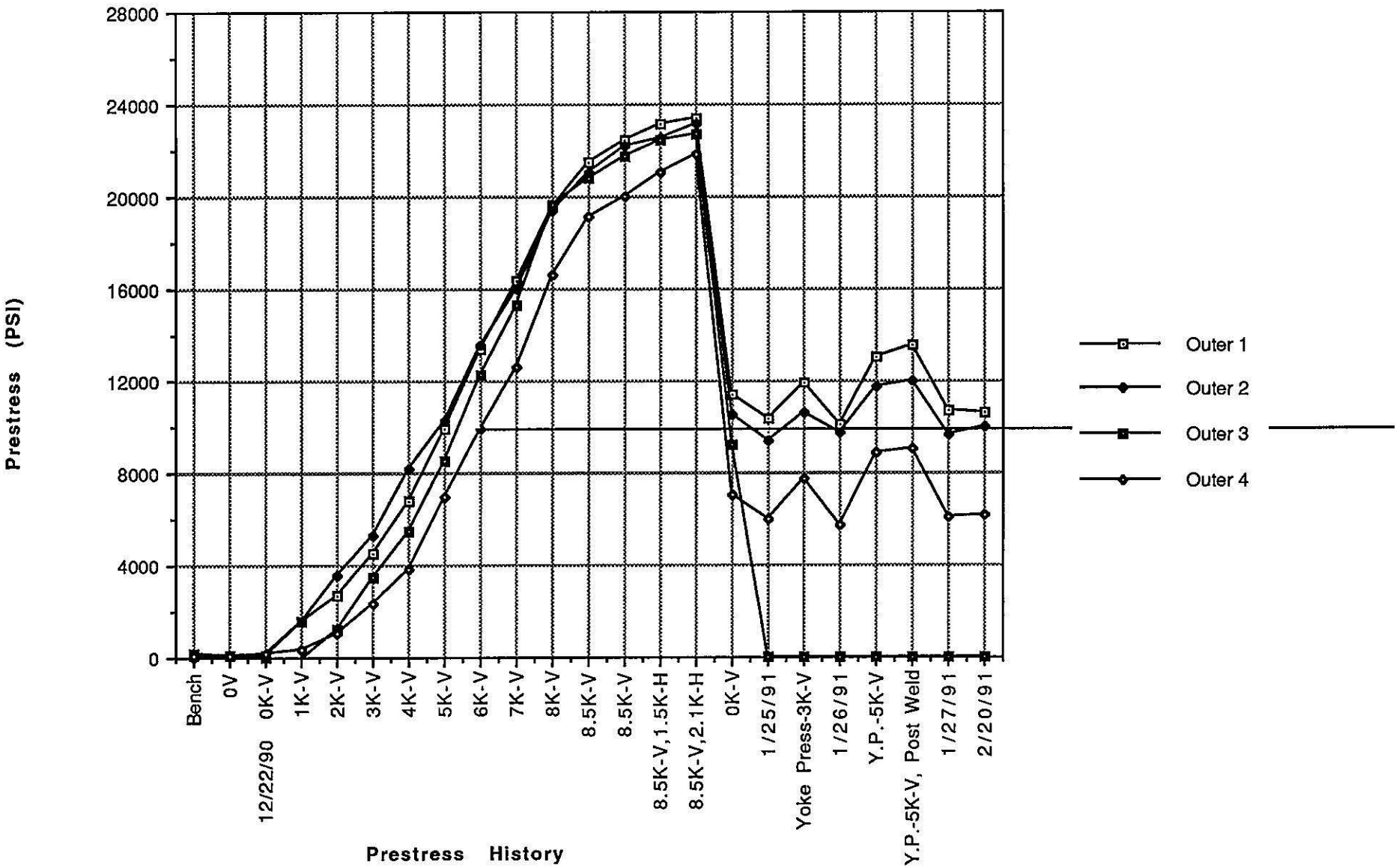


Fig 2

DC0304 Lead End Average Gage Values

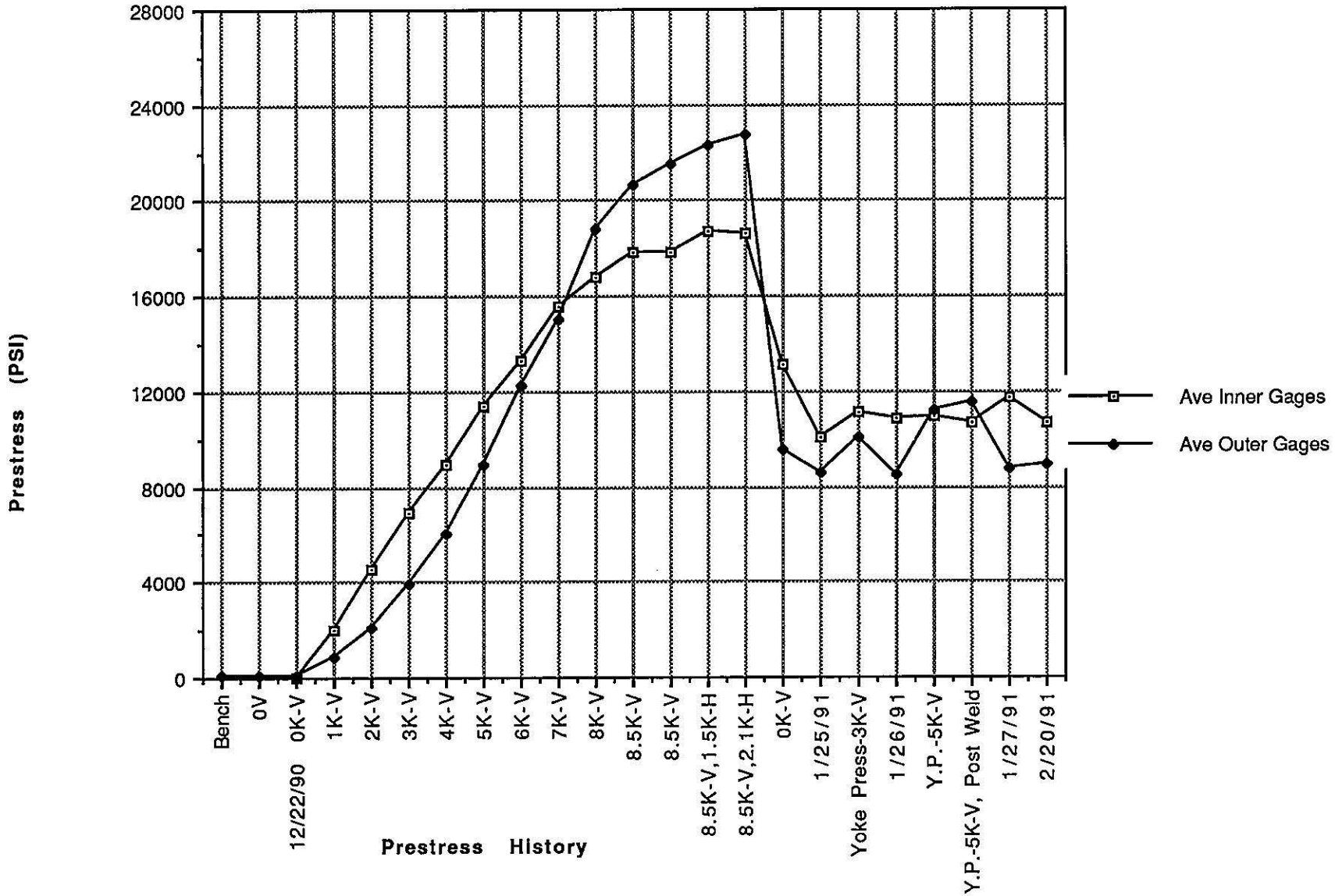


Fig 3

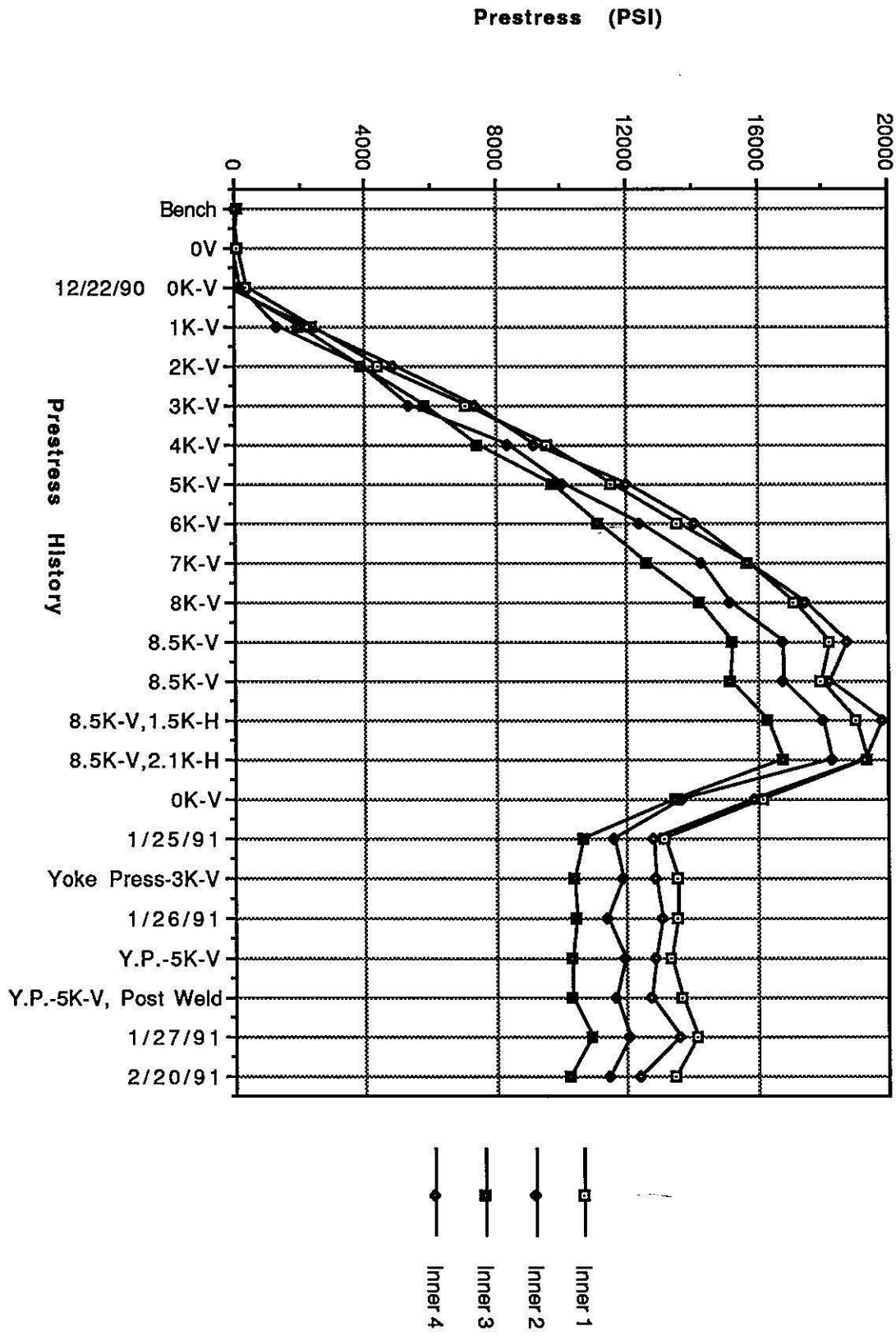

DC0304 Return End Inner Gages
Prestress (PSI)
0
4000
8000
12000
16000
20000
Prestress History
Bench
0V
12/22/90 0K-V
1K-V
2K-V
3K-V
4K-V
5K-V
6K-V
7K-V
8K-V
8.5K-V
8.5K-V
8.5K-V,1.5K-H
8.5K-V,2.1K-H
0K-V
1/25/91
Yoke Press-3K-V
1/26/91
Y.P.-5K-V
Y.P.-5K-V, Post Weld
1/27/91
2/20/91
Inner 4
Inner 3
Inner 2
Inner 1

Fig 4

DC0304 Return End Outer Gages

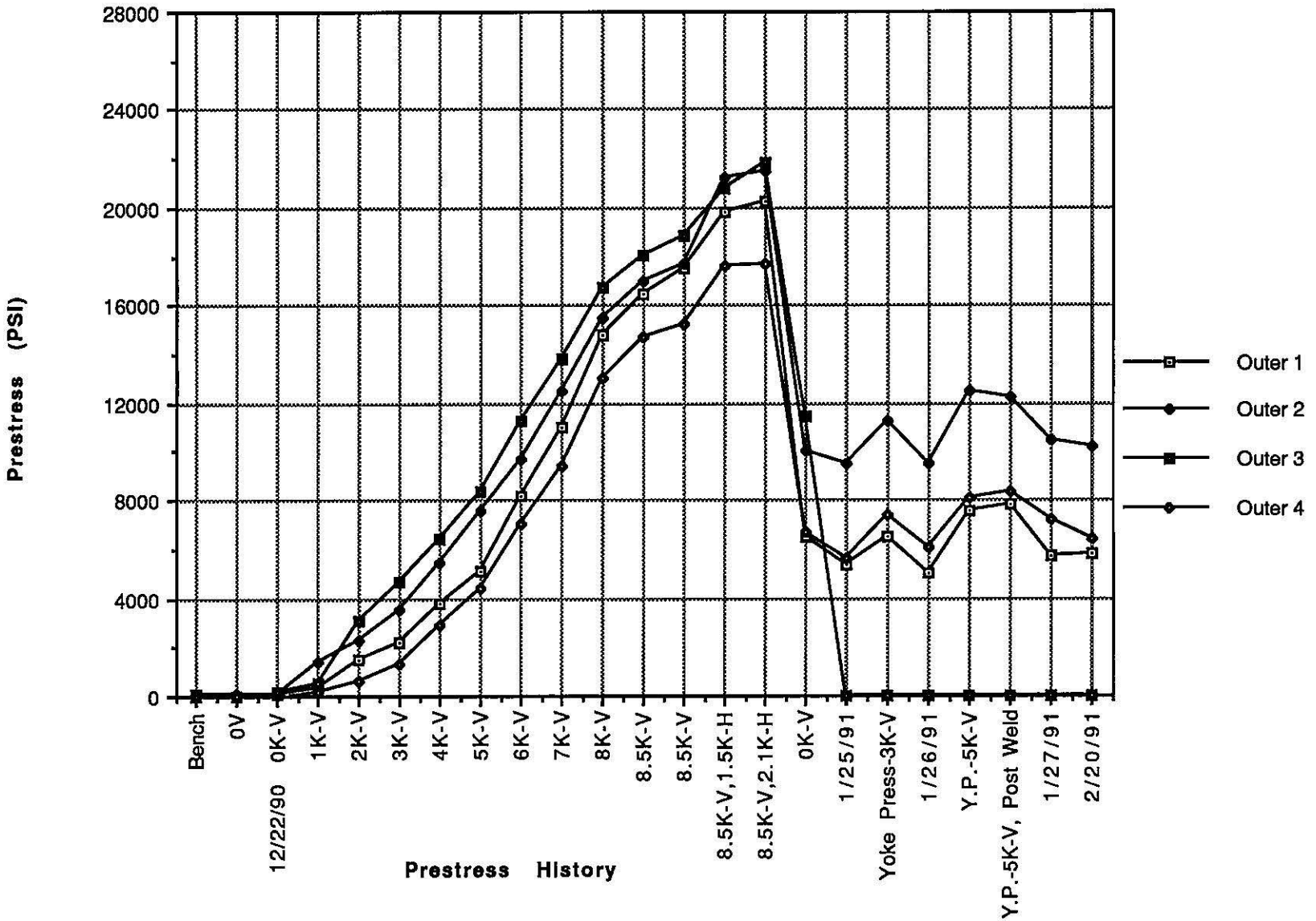


Fig 5

DC0304 Return End Average Gage Values

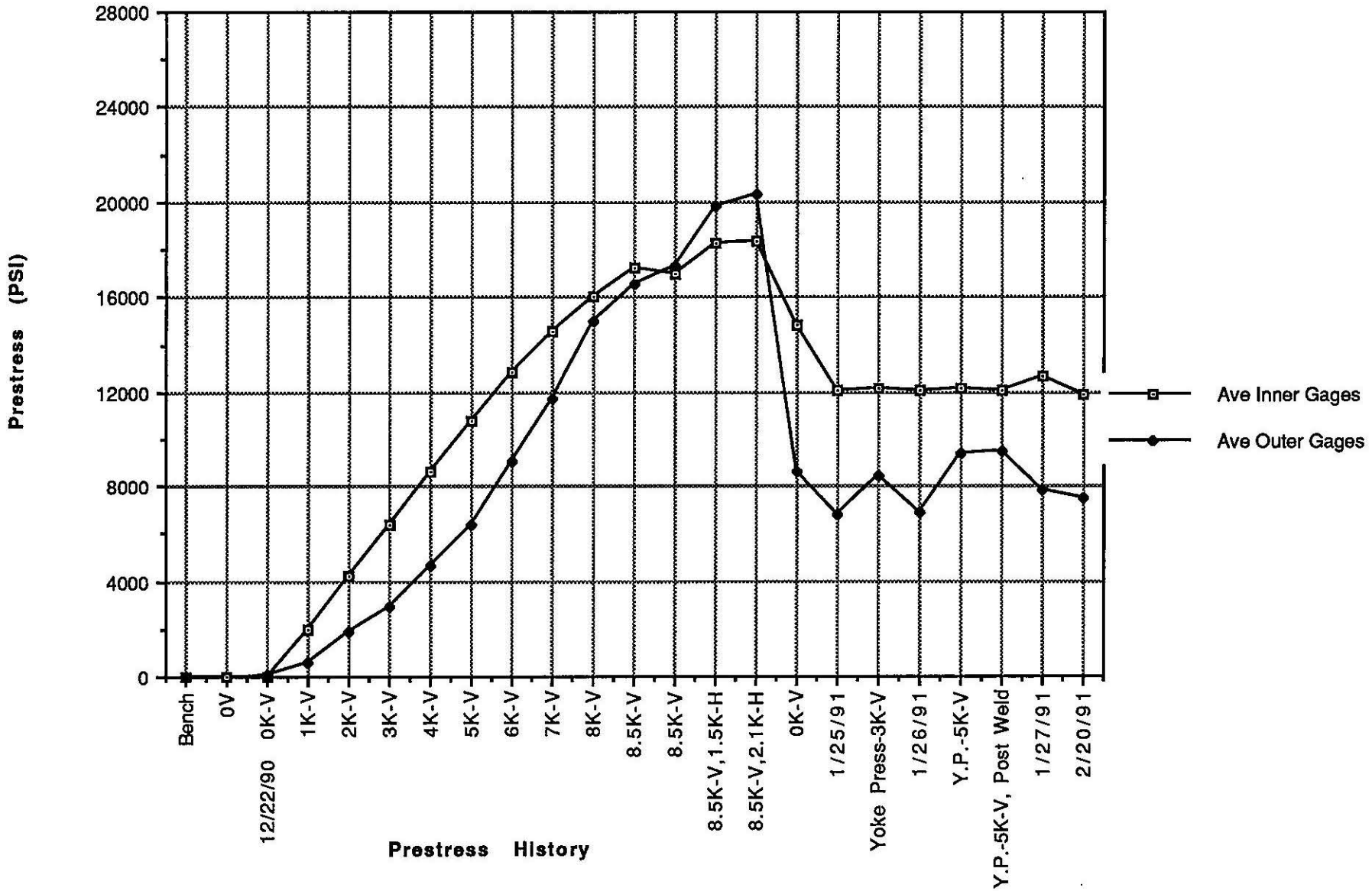
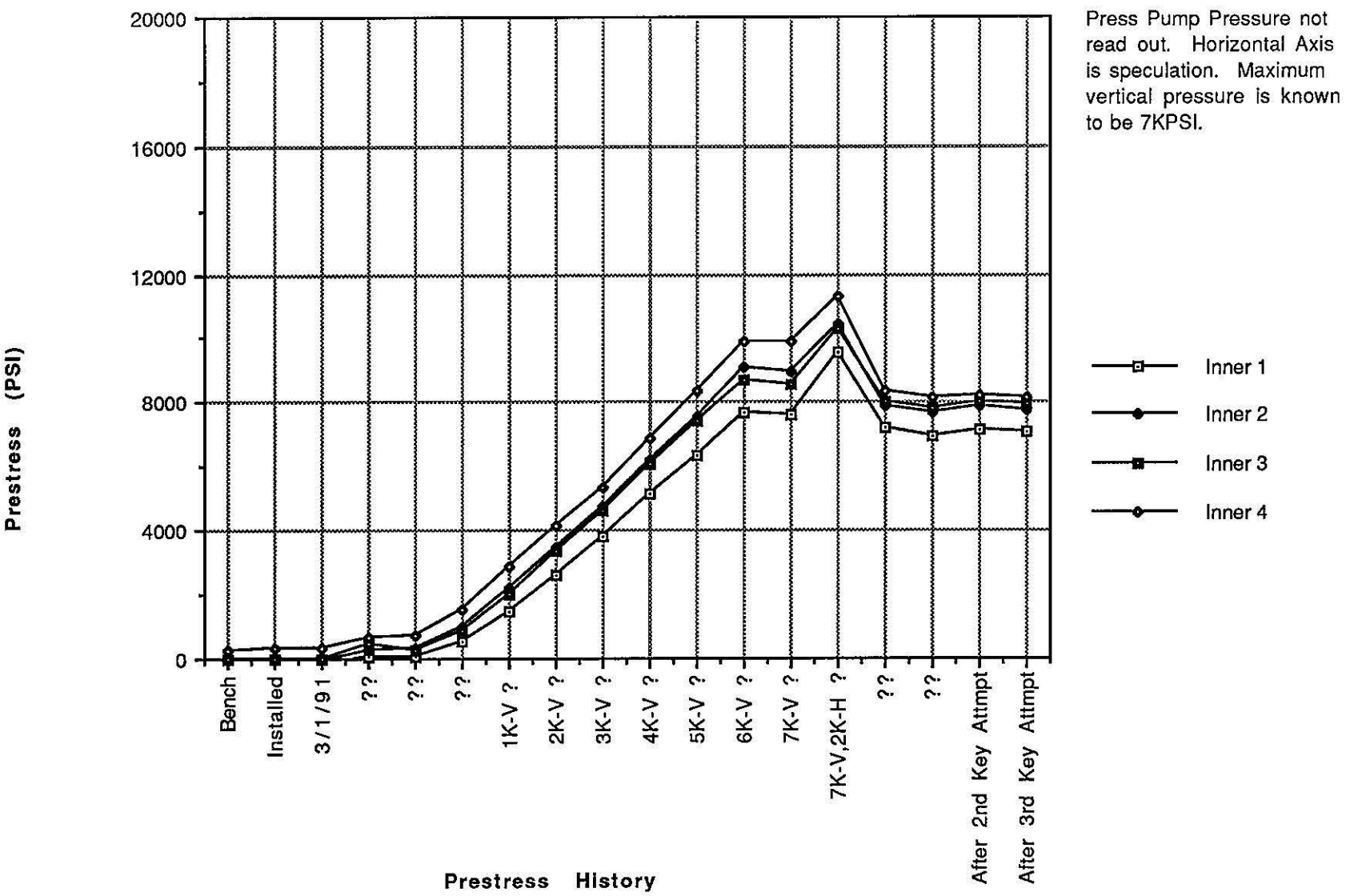


Fig 6

DC0305 Lead End Inner Gages



Press Pump Pressure not read out. Horizontal Axis is speculation. Maximum vertical pressure is known to be 7KPSI.

Fig 7

DC0305 L. E. Outer Gages

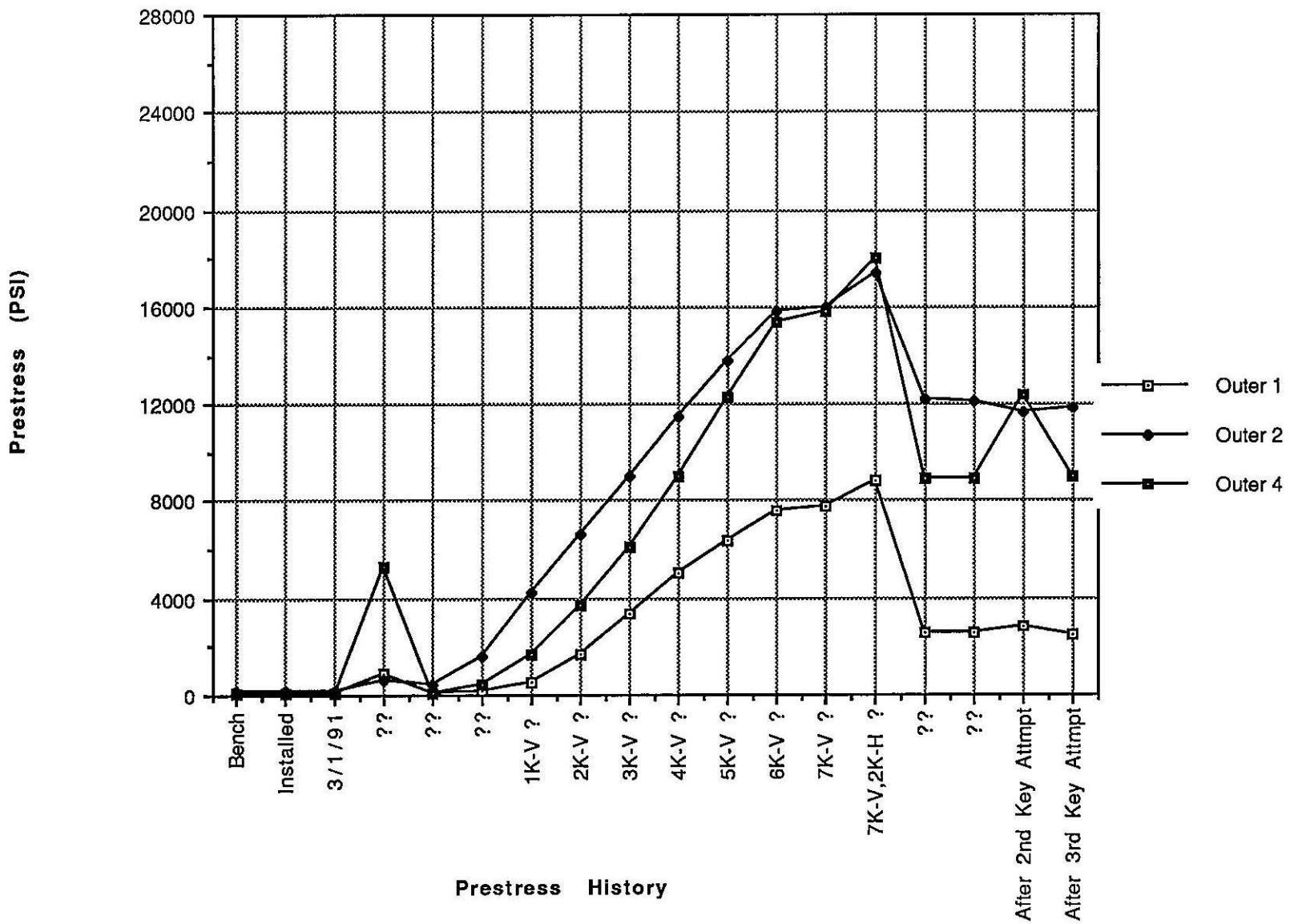


Fig 8

DC0305 L. E. Average Gage Values

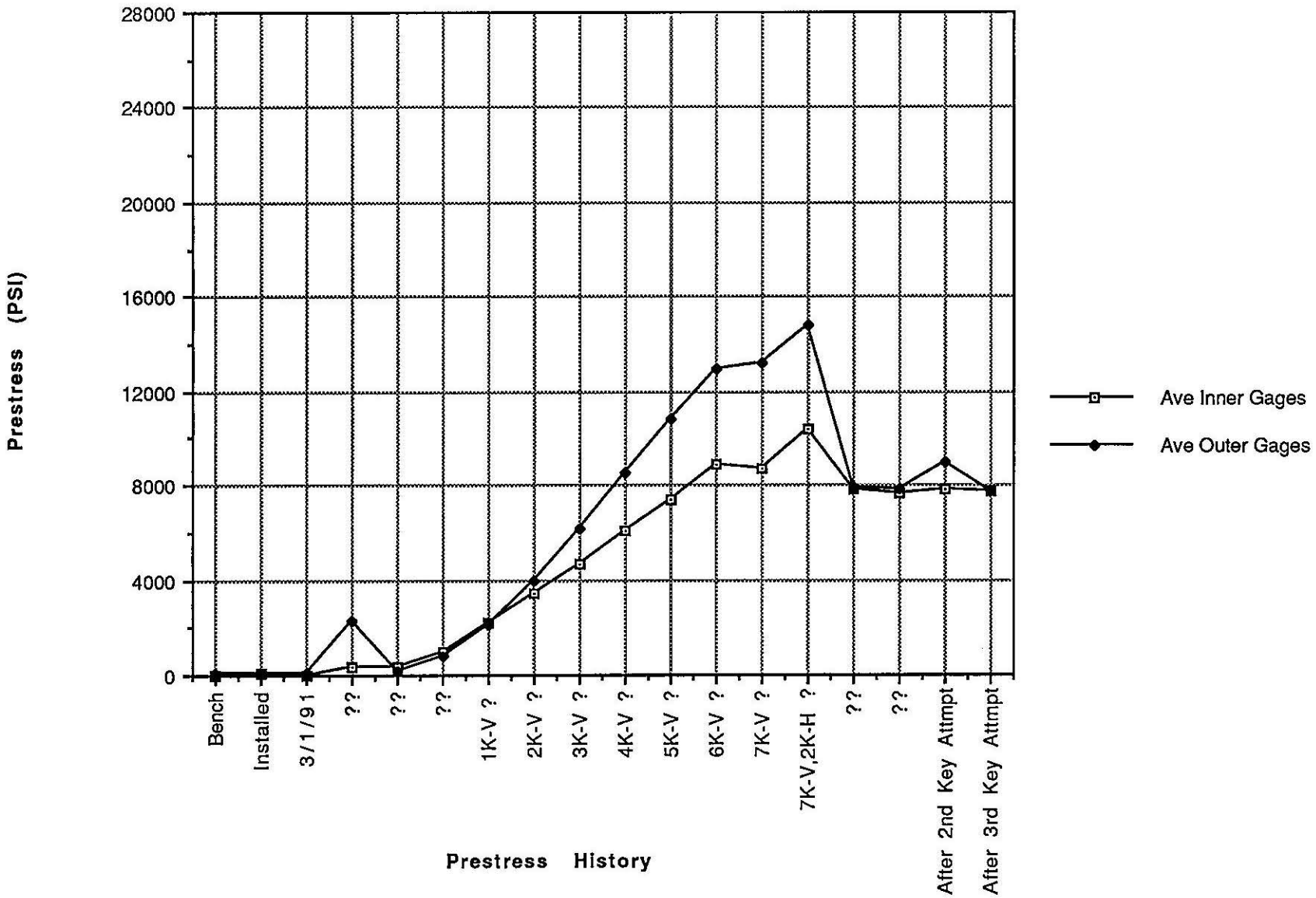


Fig 9

DC0305 R. E. Average Gage Values

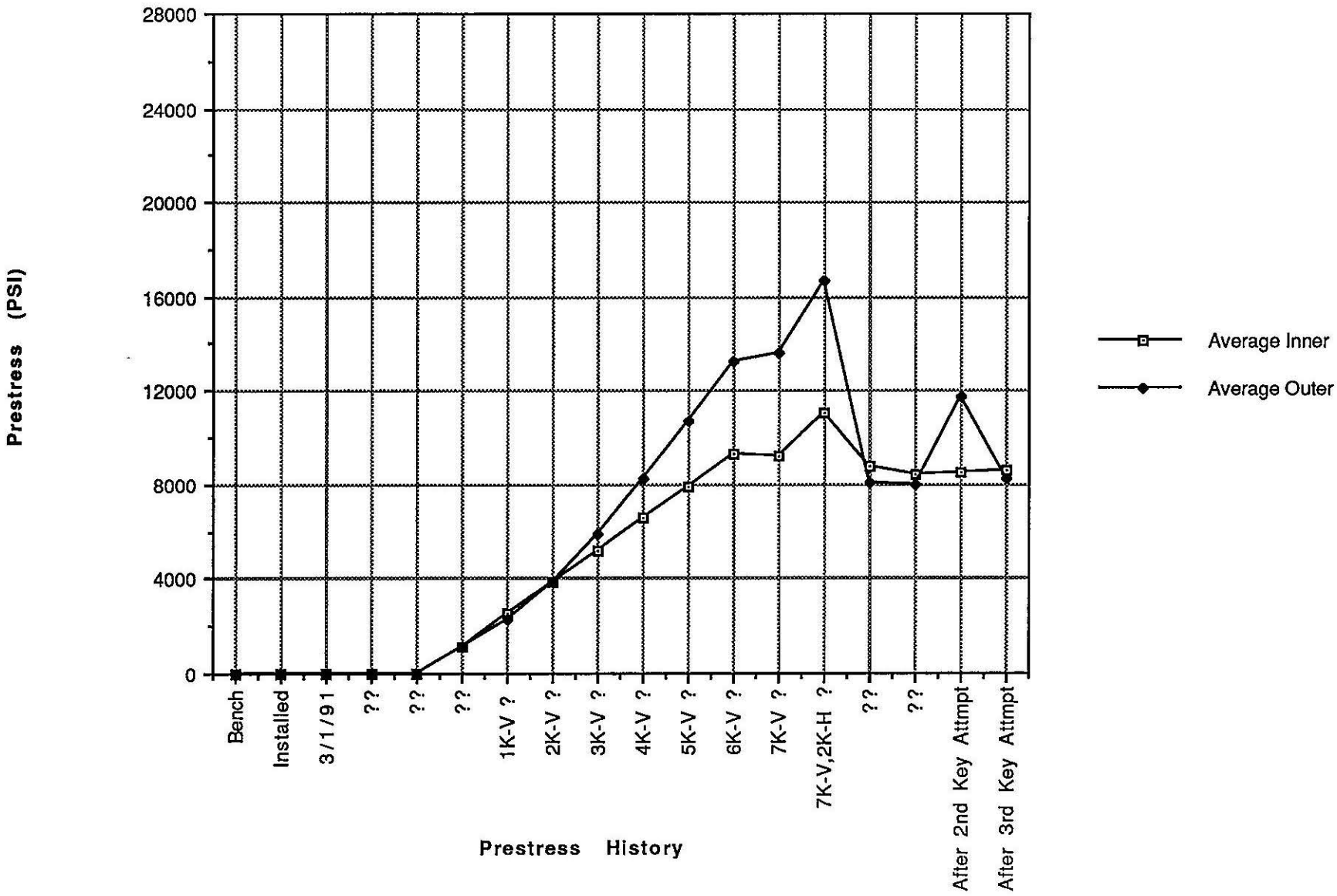
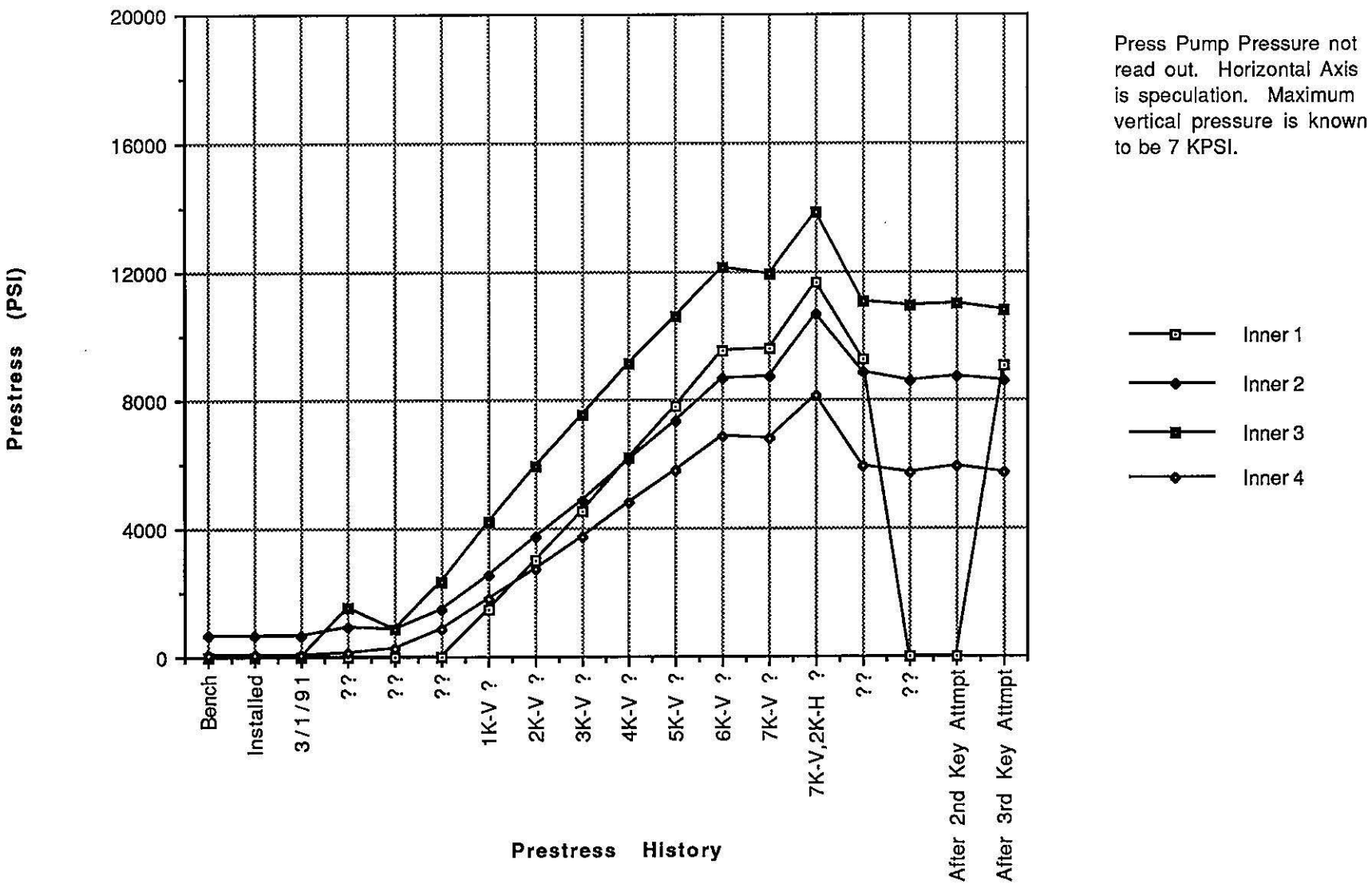


Fig 12

DC0305 R. E. Inner Gages



Press Pump Pressure not read out. Horizontal Axis is speculation. Maximum vertical pressure is known to be 7 KPSI.

Fig 10

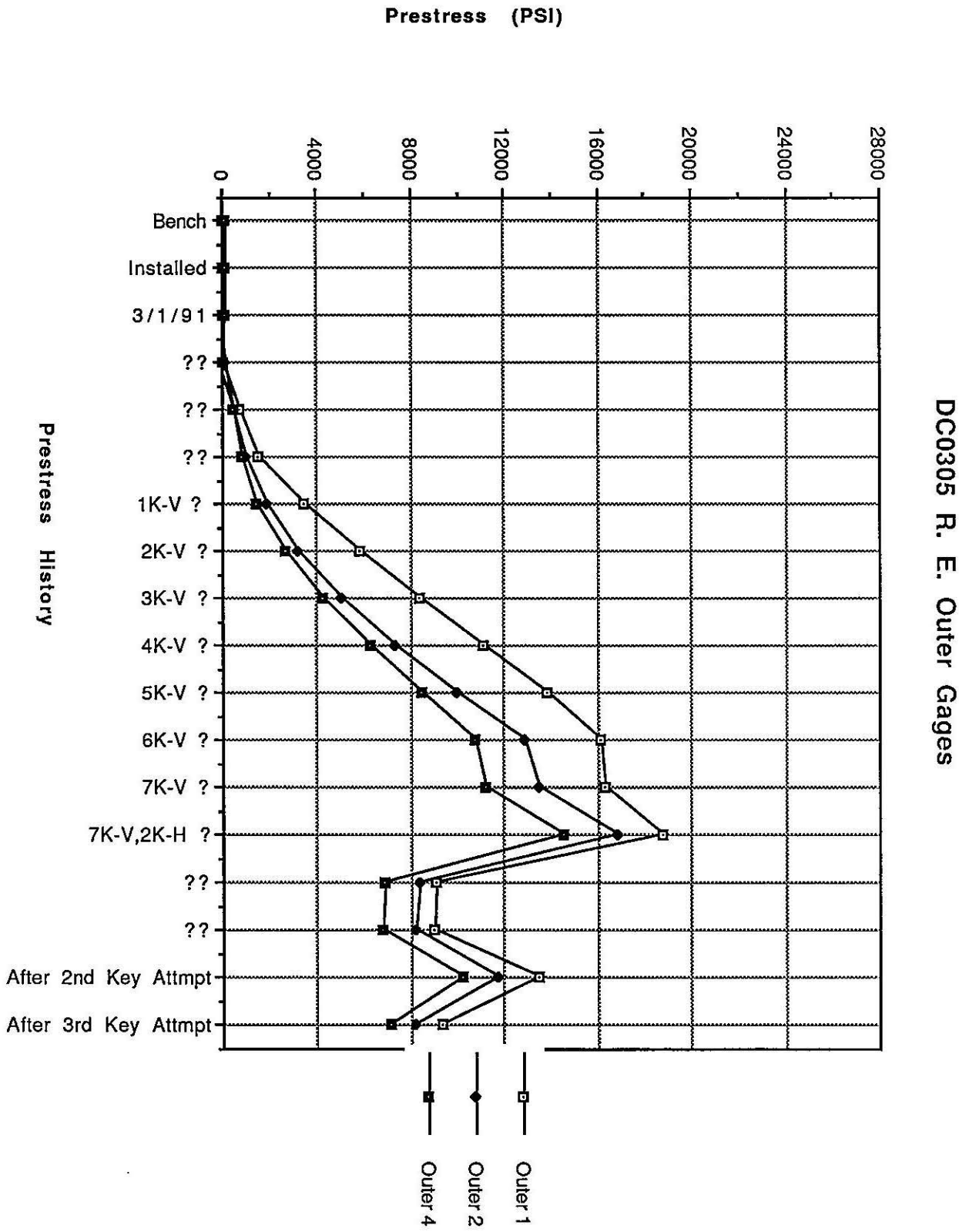

DC0305 R. E. Outer Gages
Prestress (PSI)
0
4000
8000
12000
16000
20000
24000
28000
Prestress History
Bench
Installed
3/1/91
??
??
??
1K-V ?
2K-V ?
3K-V ?
4K-V ?
5K-V ?
6K-V ?
7K-V ?
7K-V,2K-H ?
??
??
After 2nd Key Attmpt
After 3rd Key Attmpt
Outer 1
Outer 2
Outer 4

Fig 11

DC0306 Lead End Inner Gages

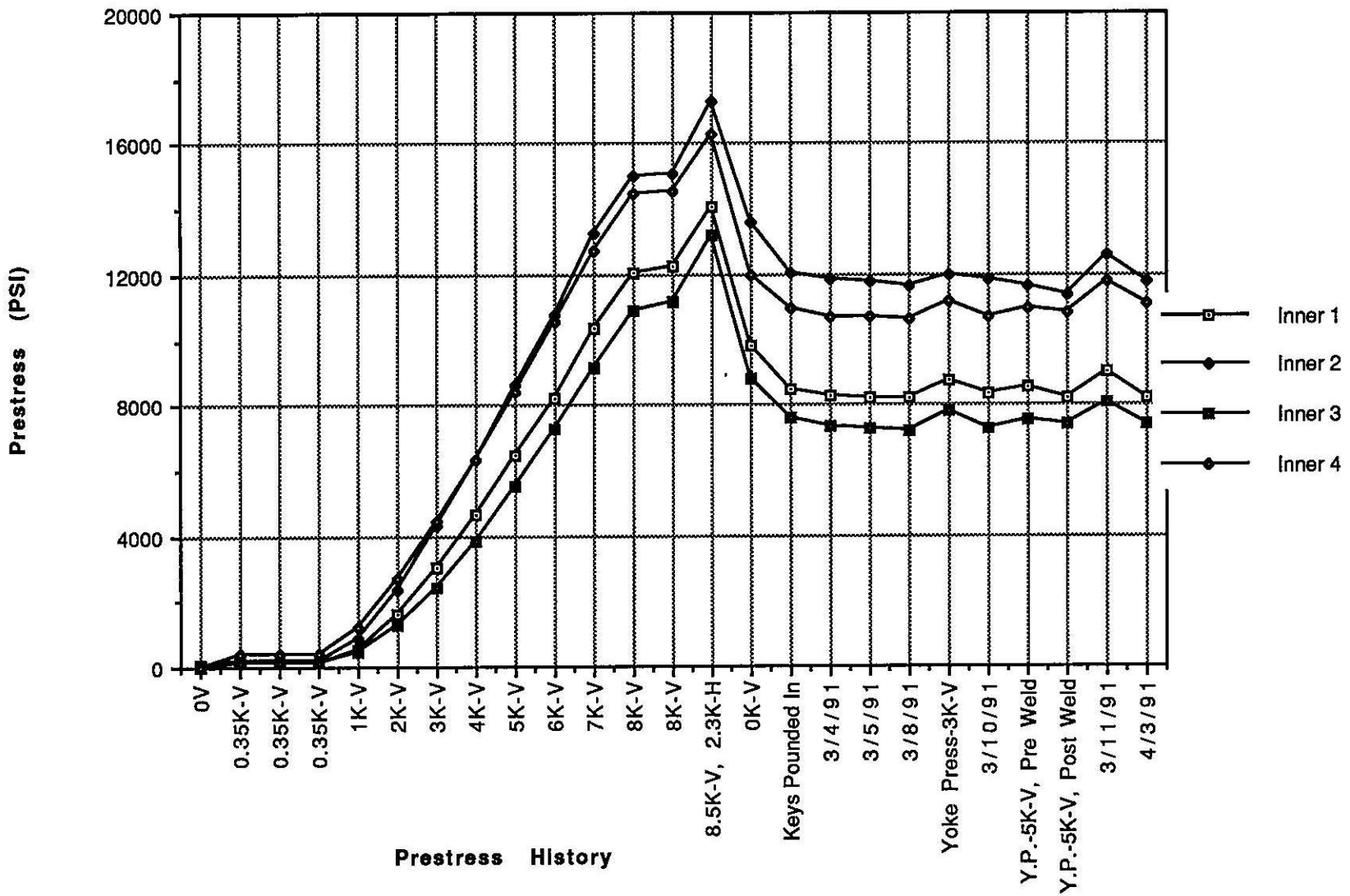


Fig 13

DC0306 Lead End Outer Gages

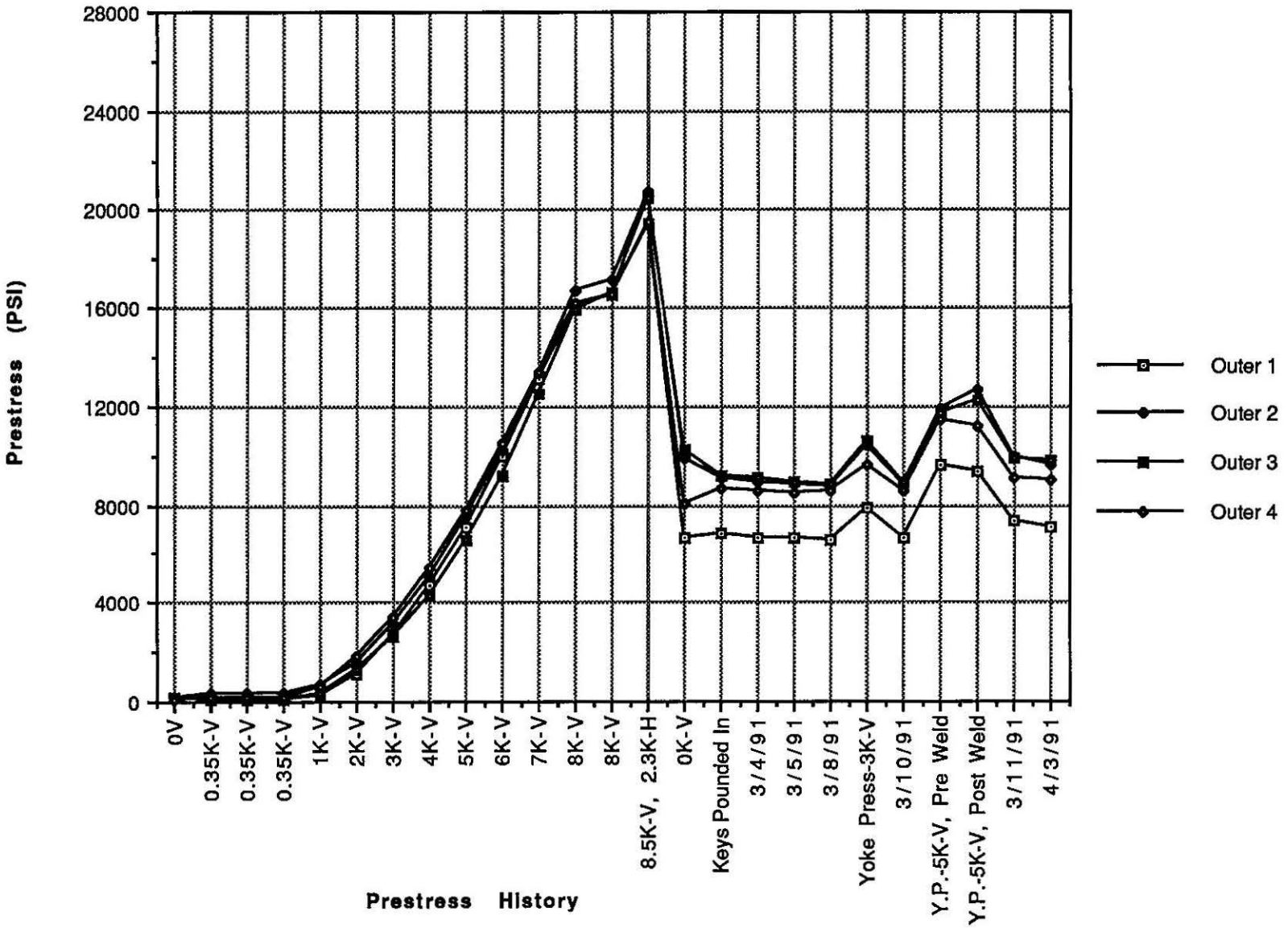


Fig 14

DC0306 Lead End Average Gage Values

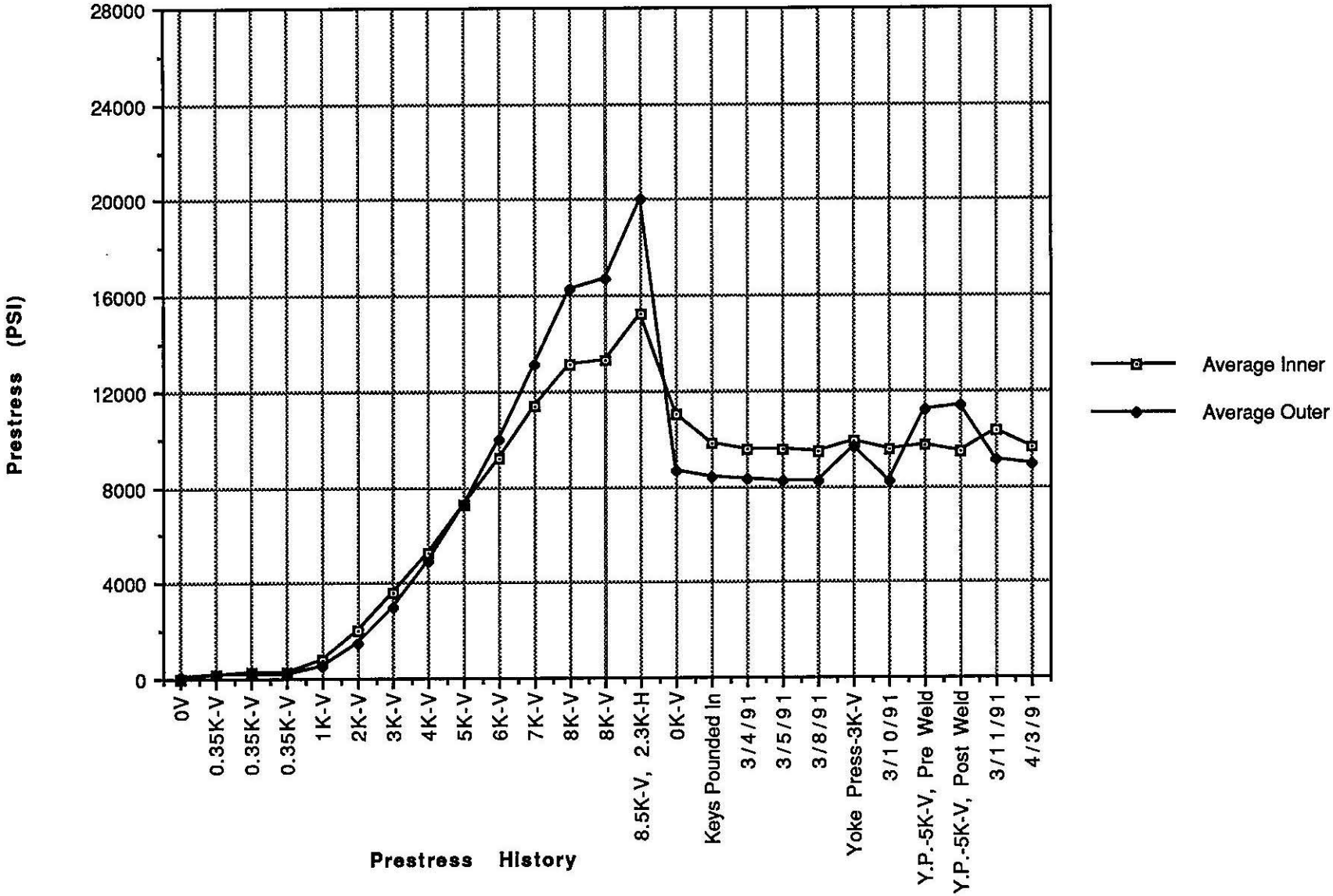


Fig 15

DC0306 Return End Inner Gages

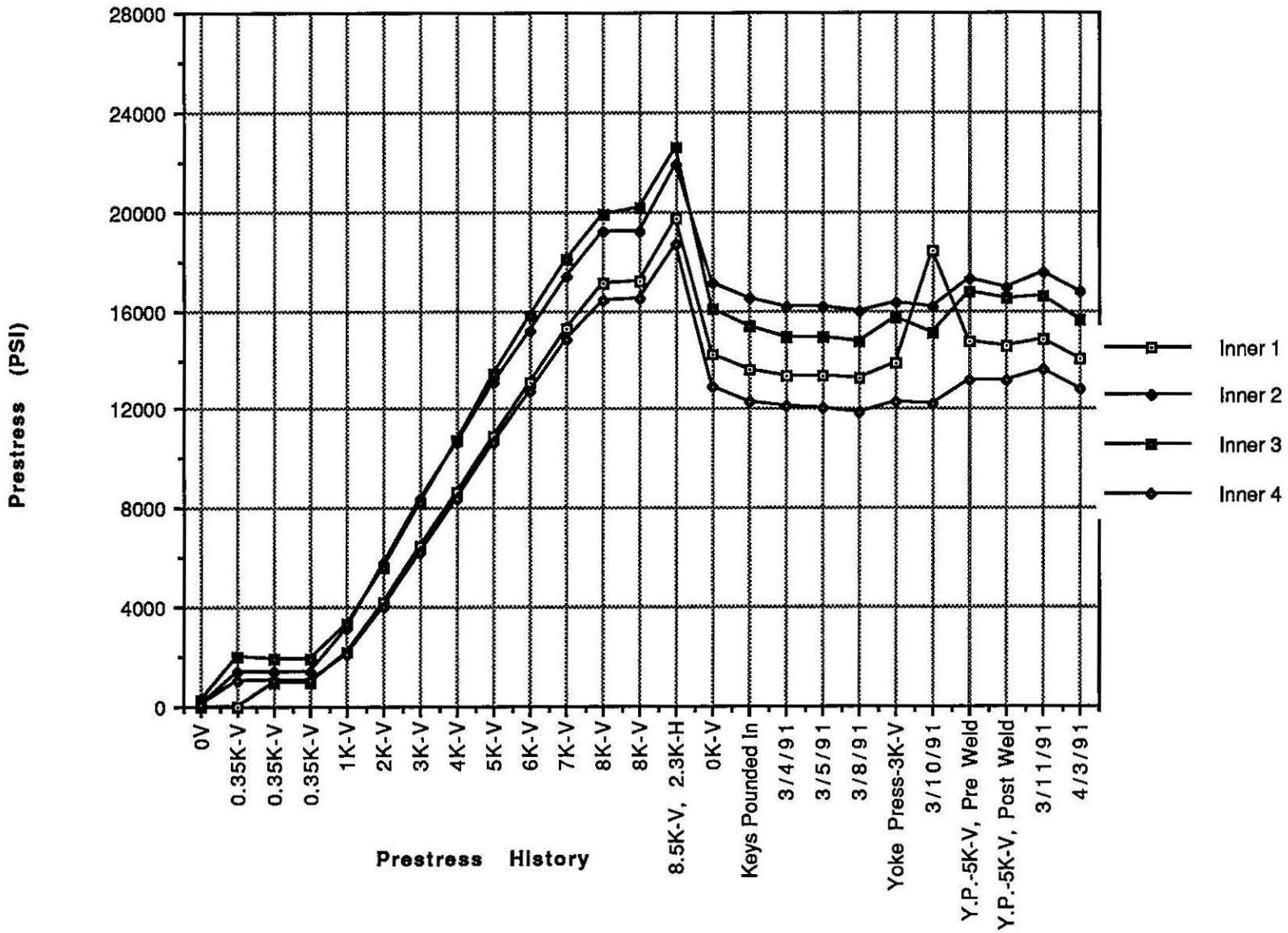


Fig 16

DC0306 Return End Outer Gages

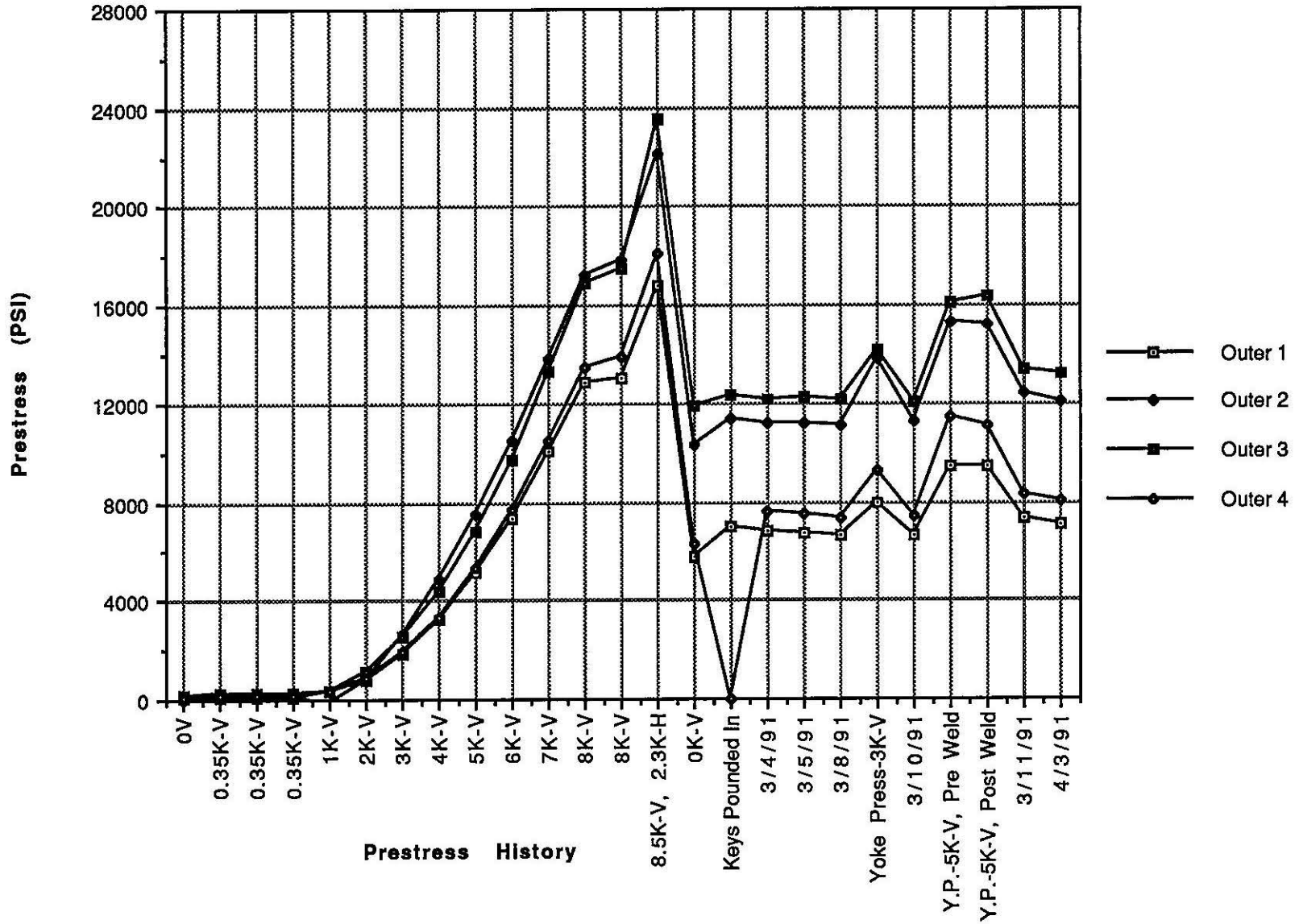


Fig 17

DC0306 Return End Average Gage Values

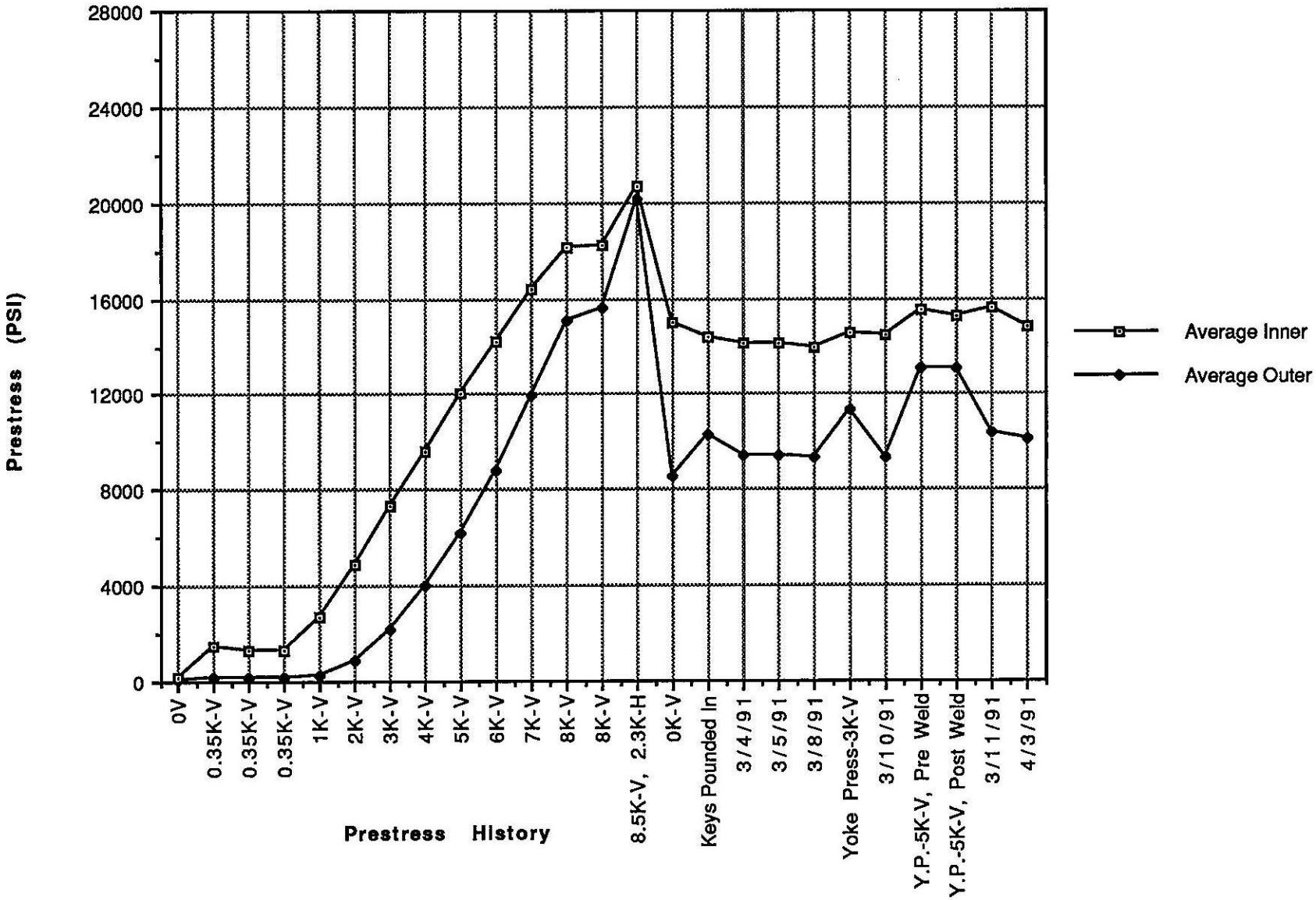


Fig 18

Coil Stress vs. Press Pressure during Keying Operation

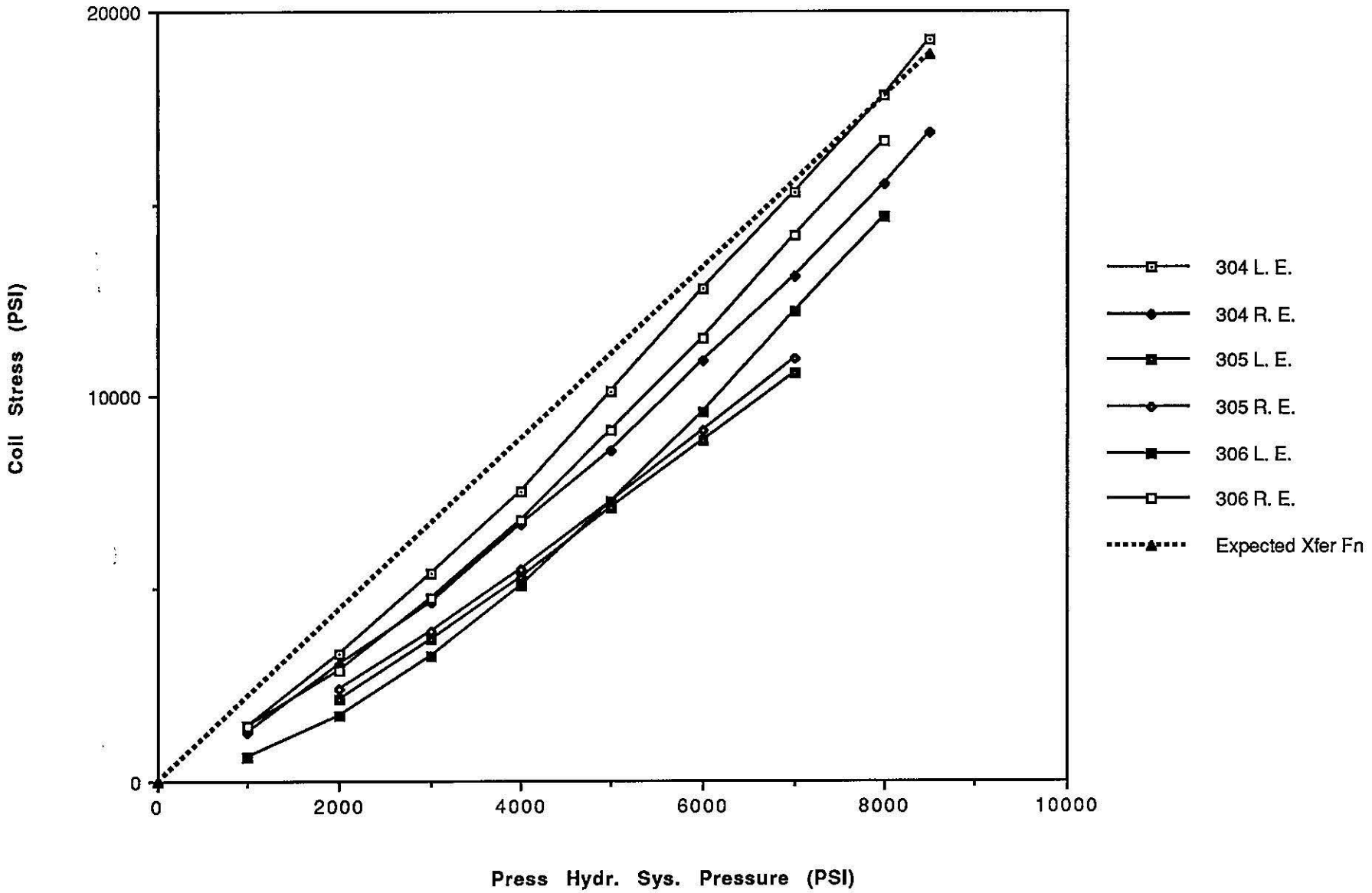


Fig 19