Fermilab

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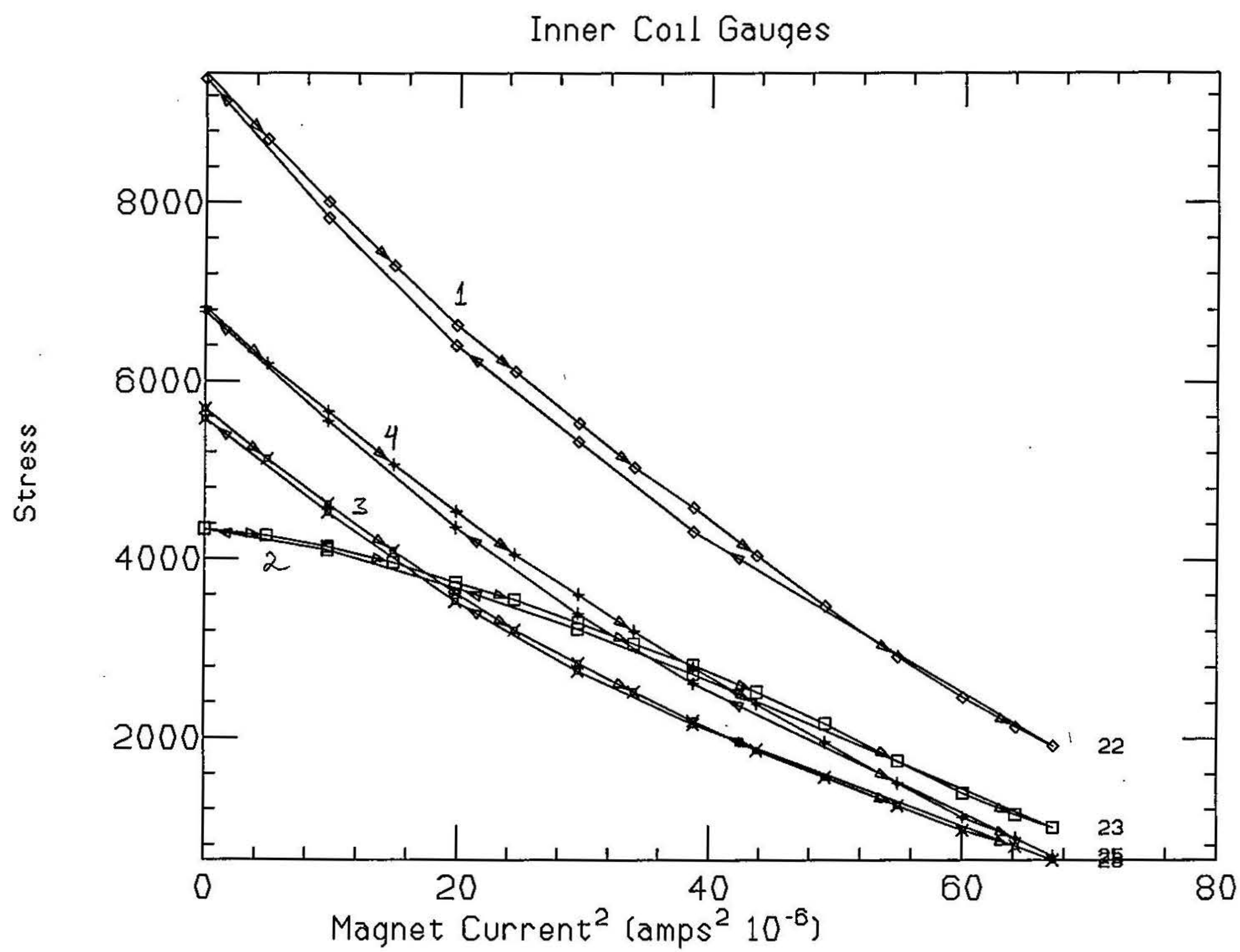
To: S.Delchamps, A.Devred, S.Gourlay, C. Goodzeit, W.Koska, M.Lamm, R.E.Sims, M.Wake, M.Winters
From: Jim Strait
Subj: Strain gauge calibration "errors"

Yesterday Arnaud complained to me about the poor quality of some of our cold strain gauge data from both 40 and 50 mm magnets. He in particular reminded me of the strange shape of the data with excitation from one of the inner coil gauges on DSA321. (See Figure 1.) To try to determine whether this shape reflects something real in the magnet or results from problems with the stress-strain calibration I recomputed the strain in the beam gauge from the raw data from one strain gauge run (DSA321.CA007) and found that the the unusual shape is absent from the strains. (See Figure 2.) Not only does the strain data from the offending gauge have a "sensible" shape, but the other three gauges show a significantly more linear strain versus I**2 than "stress" versus I**2 relation, and the spread in both initial strain and in the slope with I**2 is smaller than the spread in "stress". It would be surprising to me if the actual stress versus I**2 relation were non-linear and the stress-strain calibration of the beam gauges were non-linear in exactly the inverse way so as to generate a fortuitously linear strain verus I**2 relation.

It is conceivable that this was a problem just with DSA321 since it was put together in a great hurry. I made the same comparison of strain versus stress as a function of I**2 for DSA323 (file DSA323.CA005) and found the same effect, although it is less dramatic. Figure 3 is the coil "stress" versus I**2 (with the error in the quadratic term of the calibrations corrected) and Figure 4 is the beam strain versus I**2. As with DSA321, the strain verus I**2 is more linear and the spread among the gauges is smaller than with the "stress" data. It would be surprising if the actual spread in coil stresses were large but on two magnets the spread in stress-strain calibrations were just right to give closer agreement among the beam strains. The more likely explanation is that the stress-strain calibration is introducing significant "noise" into the data and that we might be better off using a generic and perhaps linear calibration than using individual non-linear calibrations.

Wayne has proposed a possible explanation for the apparently non-linear stress-strain relation in the calibration setup but the apparently linear relation in the magnet under excitation. He notes that the coil modulus effects the coil stress versus beam strain calibration in various ways, some of whose effects in the magnet may be more or less well simulated in the calibration setup. Since the coil modulus is a function of coil stress, particularly at low stress, this would generate a non-linear stress-strain relation in the calibration apparatus. As the force applied to the beam gauge in the calibration setup goes to zero the coil becomes uncompressed and "fluffy" and the modulus decreases significantly. However, as the magnet is excited and the force applied to the beam gauge decreases, the coil is being more, not less, compacted; its modulus stays high and in a regime in which it is a less strong funtion of stress. Thus the beam gauge calibration under these circumstances will be much more linear than that determined with a ten-stack and a hydraulic press. Just to make life more difficult, however, the coil loading during magnet assembly is rather similar to that in the calibration setup. During cooldown the decrease in the force applied by the coil to the beam gauge is accompanied also by a decrease in coil compaction. Therefore we might expect the calibration to be "correct" under this circumstance also.

Of course, the above does not address the issue of the increased spread in the data from applying the stress-strain calibration. Clearly more work is needed to understand the reproducibility (or lack thereof) of the calibrations. Given the arguements above it is not at all clear to me what sort of calibrations should be used to get the most correct pole stress data under all circumstances. This just reflects the difficulties that result from having a load cell design that is sensitive to the properties of the material whose load it is measuring. (But let me be the first to admit that I do not have a design ready that would be better than this one.)



DSA321 File: DSA321.CA007 11-JAN-91 13:19:06 24-APR-91 16:55:03

Figure 1

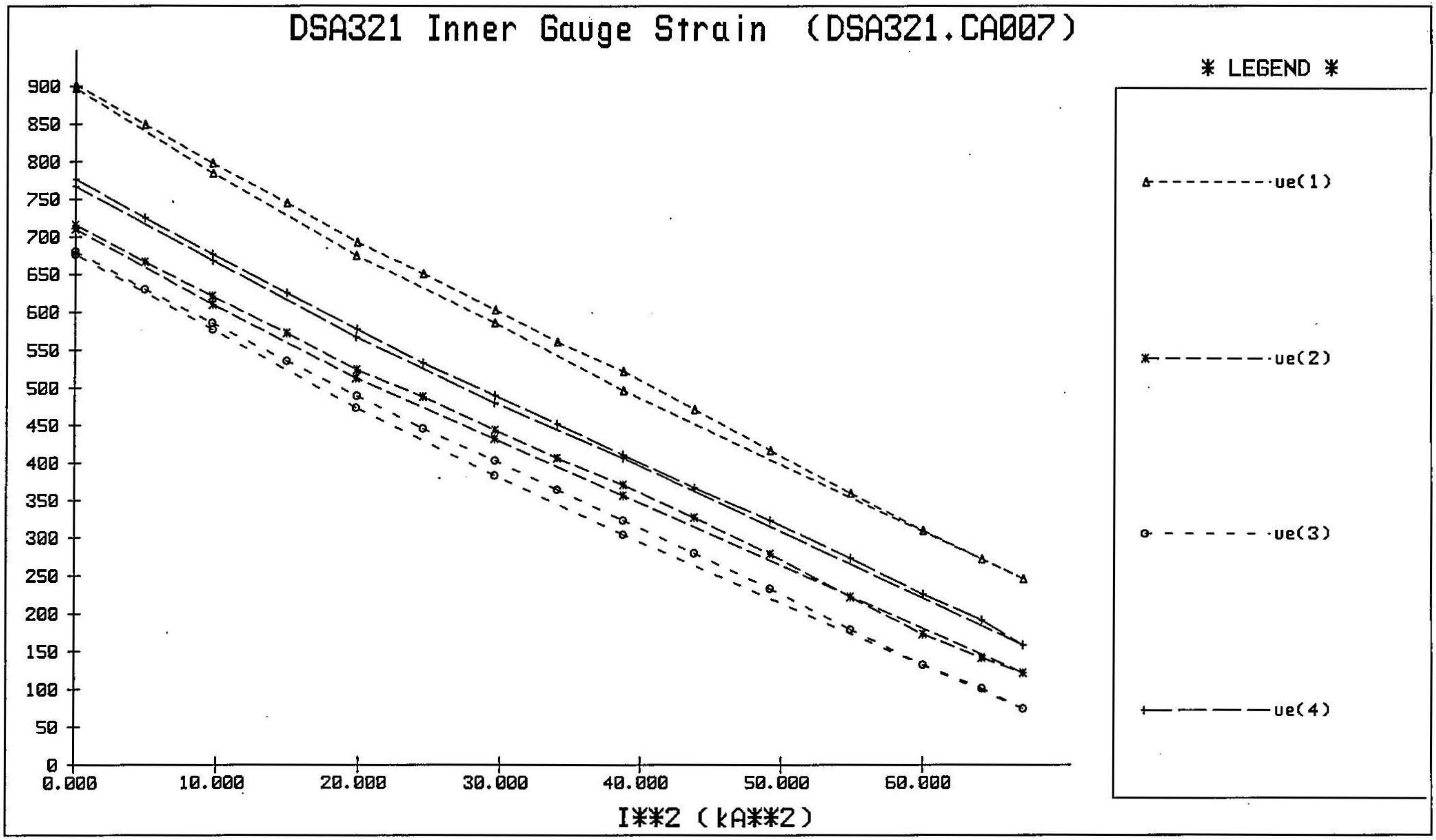

DSA321 Inner Gauge Strain (DSA321.CA007)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0.000
10.000
20.000
30.000
40.000
50.000
60.000
I**2 (kA**2)
* LEGEND *
ue(1)
ue(2)
ue(3)
ue(4)

Figure 2

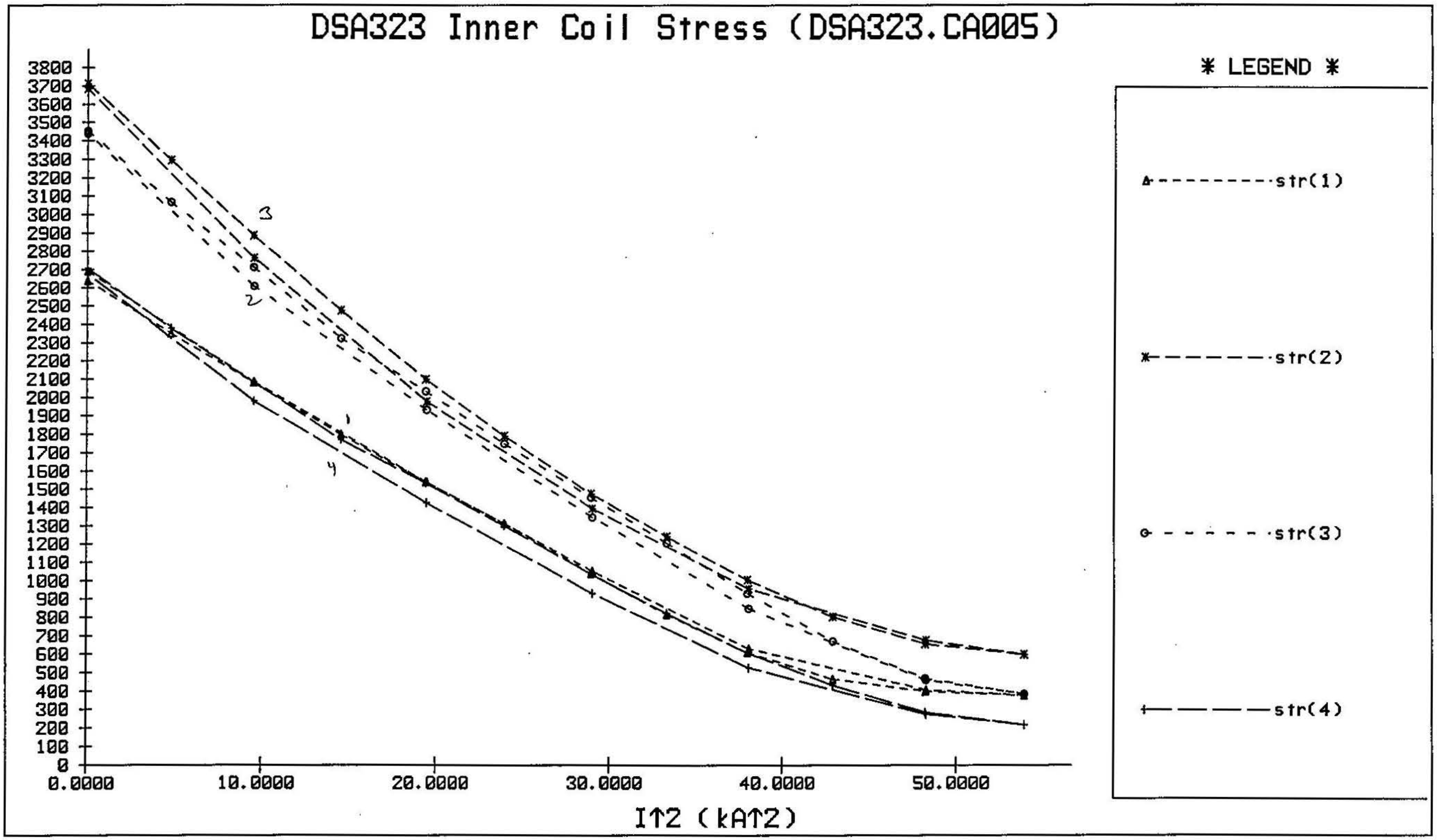

DSA323 Inner Coil Stress (DSA323.CA005)
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0000
10.0000
20.0000
30.0000
40.0000
50.0000
I↑2 (kA↑2)
* LEGEND *
str(1)
str(2)
str(3)
str(4)
3
2
1
4

Figure 3

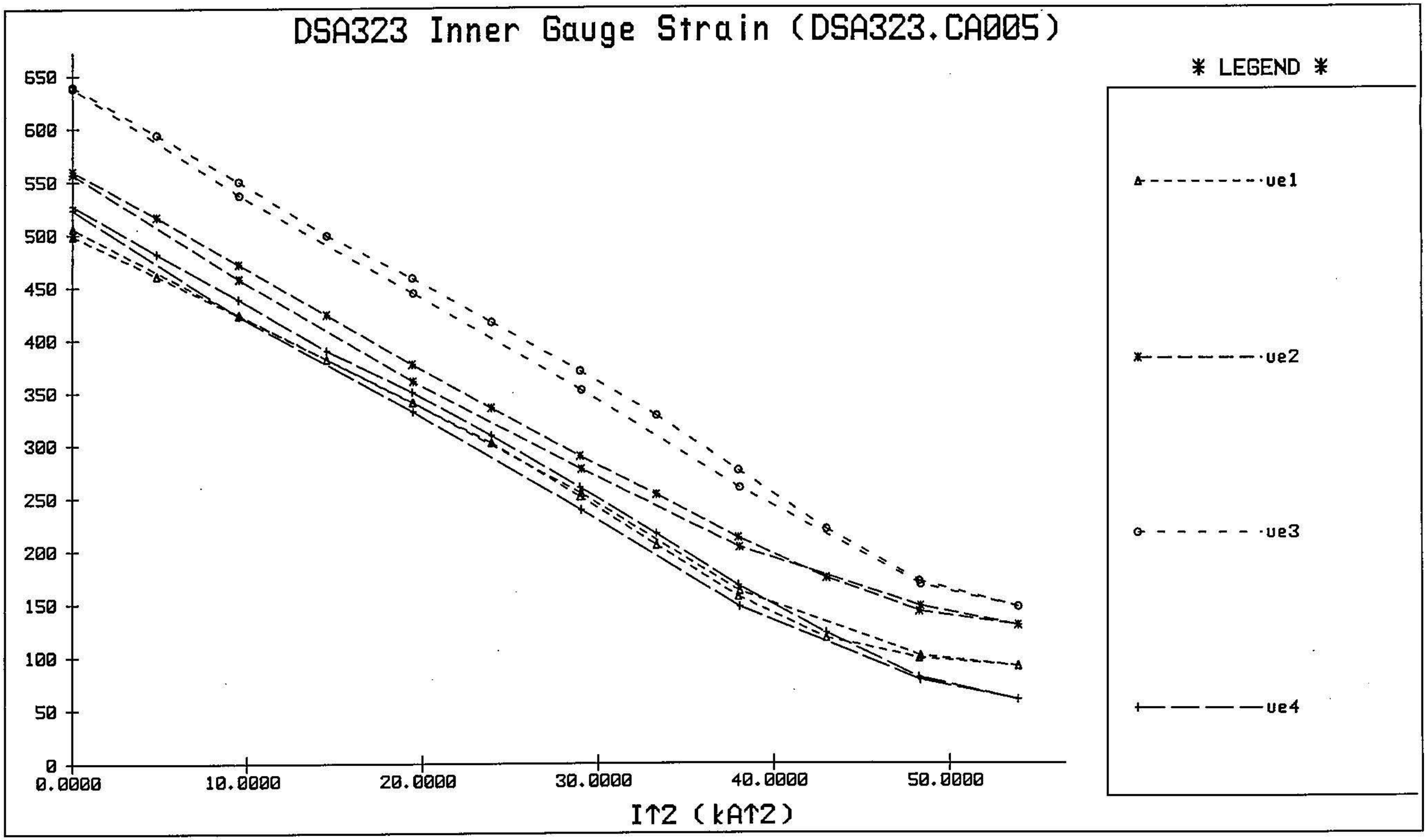

DSA323 Inner Gauge Strain (DSA323.CA005)
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0.0000
10.0000
20.0000
30.0000
40.0000
50.0000
I↑2 (kA↑2)
* LEGEND *
ue1
ue2
ue3
ue4

Figure 4