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MAGNETIC PERMEABILITY TEST OF SOME STAINLESS STEELS AT 4.2 K AND UP TO 50 kG

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The magnetic permeability (μ) of several stainless steels considered for use in the Energy Doubler/Saver has been measured in high magnetic field up to 5 T at liquid helium temperature of 4.2 K. The materials investigated were 316, Nitronic 40 and Nitronic 33. Table I gives the composition of these materials. Sheets of 62 mils thickness from the factory were cut into test size samples, and the samples were fussion welded and annealed. At each step in the process, the magnetic susceptibility of the material was determined

These sheets of stainless steel have been annealed to 1950° F for ½ hour in an inert atmosphere and water quenched at the factory. All carbide remains in solution upon water quenching and these materials do not exhibit a transition from the austenitic state or become brittle[1]. Also, none of these steels shows a transition to the ferromagnetic phase due to the influence of cryogenic cooling. The afore mentioned properties make these types of stainless attractive for use in cryogenic magnets, where field disturbance from stainless steel should be avoided. A possible drawback could be a large paramagnetism with its resultant increase in μ_r. Our measurements were done to determine if this is the case[2].

The measuring apparatus consists of two nearly identical pickup coils bucked against each other and suspended within the uniform field region of a superconducting solenoid[3]. Any fine adjustments between two coils are made with external electronics. The magnet is slowly ramped and the coils are adjusted so that no signal is obtained when no sample is present. A typical sample size was 5 cm long and 1.5 cm in diameter. The integrated output from the pickup coils versus the magnetic field due to the solenoid is plotted on an X-Y recorder. The output voltage is directly proportional to the difference in magnetic susceptibilities of the materials within the pickup coils.

The factory processed sheets of Nitronic 40 and 33 had similar μ's which were approximately one eighth that of the 316. Magnet clamping collars had been made from the 316 stainless and some of these were cut into samples to test the effect of punching. There was no difference in the susceptibility of the samples taken from the sheet and the collars. Welding had no effect on the 316, but caused dramatic low field increases in the Nitronic 33 and 40 samples. The area affected by the weld was calculated for each sample. After annealing to 1950° F (1066° C) and water quenching the susceptibilities of the Nitronics showed a large decrease, but were still larger than the non-welded samples. The magnetic susceptibilities of the various samples were measured from 0 to 5 T. The data, without the corrections described later, are presented in Table II and also in Fig. 1 and Fig. 2.

Based on sample dimensions, the calculated correction due to demagnetization effect is about 7% of the susceptibility for the samples tested. This gives a correction in μ_r, the magnetic permeability, ranging from .01% for the non-welded Nitronics at high field to .7% for the welded Nitronic 40 at fields below .05 T. Another error is introduced by the effective area of the pickup coil being larger than the cross-sectional area of the sample. Part of the flux excluded from the sample would still be enclosed by the pickup coil. This effect is expected to result in a change of perhaps 7% in the output voltage. This was demonstrated when samples of lead with dimensions very close to these of the welded and annealed samples were measured and had μ_r-1, ranging from -.94 to -1.07. Other small errors whose cumulative affect may be 5 to 10 percent of the output voltage include integrator drift, slight inhomogenities in the magnetic field and cable resistance. The total effect, if all errors are additive, would be approximately 20% of the output voltage and, hence, of the magnetic susceptibility.

The 316 stainless has a magnetic permeability which is too high to be acceptable in our applications. The non-welded samples of the Nitronics are very good over the whole operating range, but welding makes them unacceptable. After annealing, Nitronic 33 is not acceptable at fields below 0.12 T and Nitronic 40 at fields below 0.3 T where each has μ_r-1 greater than 0.01. Below .05 T, the welded but not annealed Nitronics show a constant μ_r. 316 has a constant value of μ_r for fields down to .05 T or lower. Modifications in the annealing process need to be investigated in order to produce acceptable magnetic properties in the Nitronics down to zero field.

References

[1] G. Biallas: Private communication.

[2] After this measurement, we were told about similar works by other people on other types of stainless steel. D.C. Larbalestier and H.W. King; RHEL/R 217 (1971) and Cryogenics 10 (1973) 160.

[3] M.E. Price and R. Yamada: Hysteresis Loss Test of Superconducting Wires, TM-639, December 15, 1975.

Table I

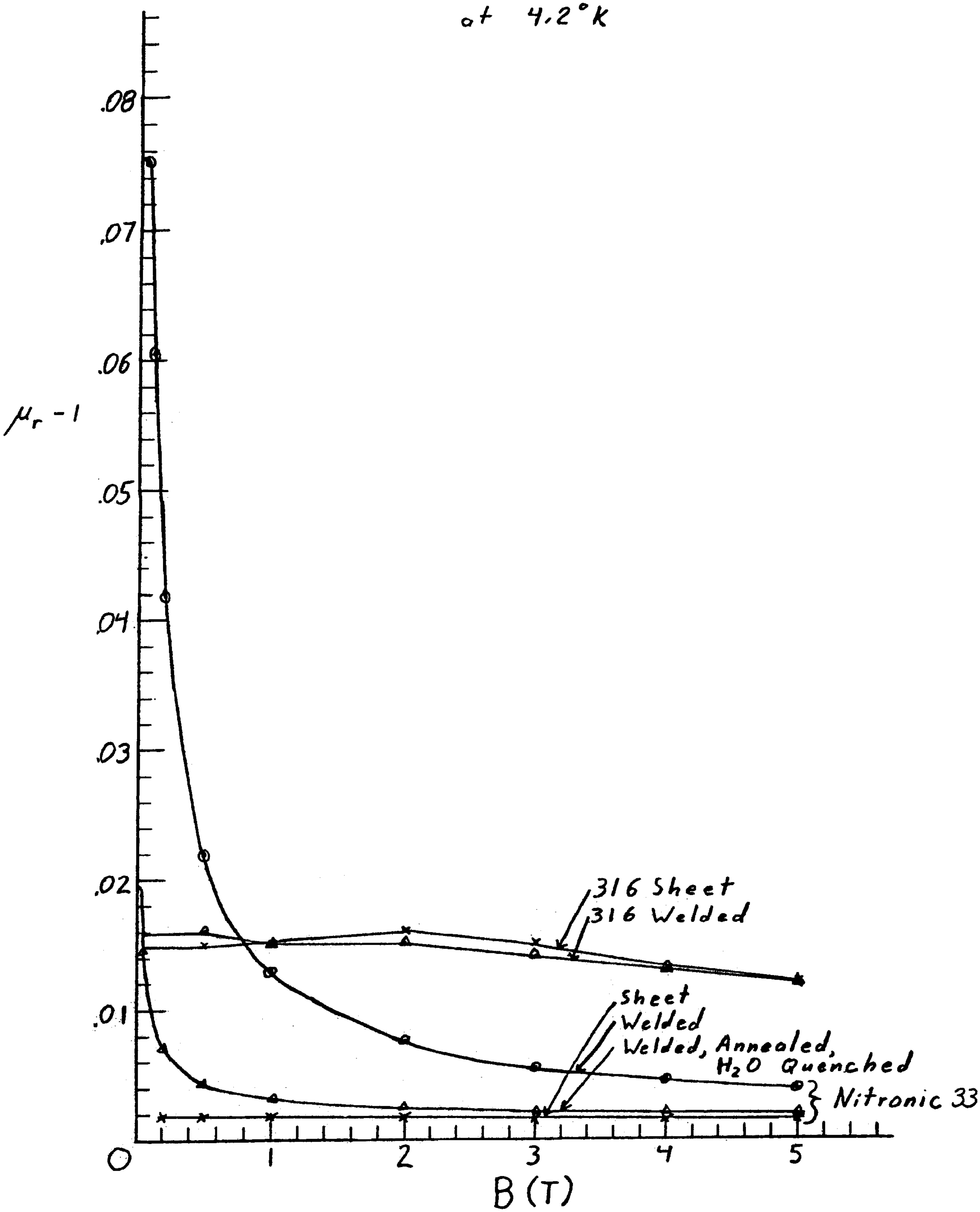
	Cr	Ni	Mn	Fe	Other
316	16-18	10-14	≤ 2	62-70	Si ≤ 1 C ≤ .08 Mo 2-3
Nitronic 40	21	7	9	62	
Nitronic 33	18	3	13	65	

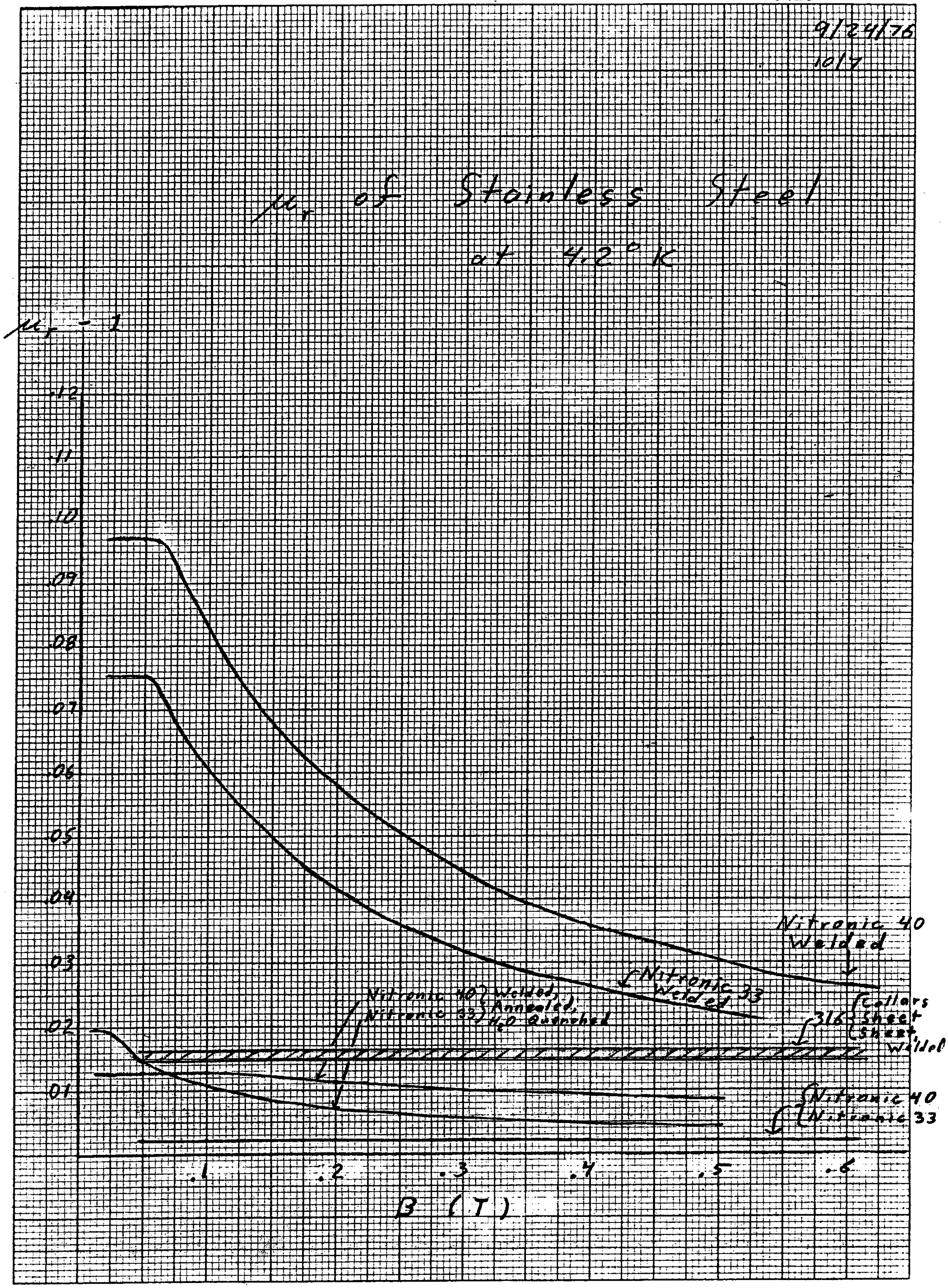
Table II

SUSCEPTIBILITY OF VARIOUS STAINLESS AT 4.2 K , $\mu_r - 1$

Alloy	.2T	.5T	1T	2T	3T	4T	5T
As Cut From Sample							
Nitronic 40	.0022	.0021	.0021	.0020	.0019	.0018	.0018
Nitronic 33	.0019	.0019	.0018	.0017	.0016	.0015	.0015
Welded-Annealed							
Nitronic 40	.0113	.0084	.0053	.0036	.0031	.0028	.0025
Nitronic 33	.0070	.0043	.0032	.0024	.0020	.0019	.0018
Both Of The Above Classes							
316	.015	.015	.015	.016	.015	.013	.012

Fig. 1 μ_r of Stainless Steel at 4.2°K




9/24/76
10/7
μr of Stainless Steel
at 4.2°K
μr - 1
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.1
.2
.3
.4
.5
.6
B (T)
Nitronic 40
Welded
Nitronic 33
Welded
Nitronic 40 } Welded,
Nitronic 33 } Annealed,
H2O Quenched
316
Collars
Sheet
Sheet,
Welded
Nitronic 40
Nitronic 33