configurations have been used for shock-demagnetization measurements. Novikov and Mineev [74N3] have used a configuration similar to Royce's (4.7b), with a thick-sample variant calibrated by static compression of iron powder mixed with organic encapsulants. Kiselev [75K1] has extended Grady's technique (fig. 4.7d) to a pressure of 33 GPa by placing the entire assembly in an impedance-matching tungsten-paraffin mixture and using an external electromagnet for excitation. Wayne [69W1] has improved upon the analysis of data from the laminated core configuration (fig. 4.7c) by static calibration studies.

A summary of shock-demagnetization investigations is shown in table 4.6. An overall perspective of the effect of pressure on magnetization can be obtained by considering the comprehensive static-high-pressure studies of the pressure derivatives of magnetization in the iron–nickel alloy system. These studies, which are summarized in fig. 29 of the review by Duvall and Graham [77D6], show that alloys having nickel concentrations less than about 28 atomic per cent are stable in the bcc phase and their magnetizations are not sensitive to pressure. When nickel concentration exceeds about 28 atomic per cent, the alloys are stable in the fcc phase but only in the composition range of 28 to 40 atomic per cent nickel are the magnetizations sensitive to pressure. Thus, we expect Curie-point transitions in the fcc alloys at pressure less than, say, 40 GPa in only a limited number of alloys. In the bcc ferromagnetic iron alloys the well-known shock-induced bcc → hcp ($\alpha \rightarrow \varepsilon$) transition is well characterized and this transition would be expected to dominate the behavior of these materials. A summary of these first-order polymorphic phase transitions is given by Duvall and Graham [77D6].

Table 4.6
Observations of shock-induced demagnetization

Materials[a]	Authors	Method[b]
Second-order phase transitions (fcc iron alloys)		
35% Ni 65% Fe (Invar)	Curran [61C1]	I
35% Ni 65% Fe (Invar)	Graham [68G3]	III
35% Ni 65% Fe (Invar)	Clator and Rose [67C3]	III
28.4% Ni 71.6% Fe	Graham et al. [67G2]	I
28.4% Ni 71.6% Fe	Wayne [69W1]	III
$Fe_{0.65}(Ni_{0.94}CO_{0.06})_{0.35}$	Edwards [78E1]	III
$Fe_{0.65}(Ni_{0.92}CO_{0.08})_{0.35}$	Edwards [78E1]	III
49% Ni 51% Fe (Deltamax)	present work	III
First-order phase transitions (bcc iron alloys)		
Iron	Royce [68R4, 71R3]	II
Iron	Wong [69W2]	—
6.3% Si 93.7% Fe (Silectron)	Graham [68G3]	III
6.3% Si 93.7% Fe	Kiselev [75K3]	IV
28.4% Ni 71.6% Fe	present work	III
10% Mn 90% Fe	present work	III
Iron powder/bakelite mixture	Novikov and Mineev [74N3]	II
Stress-induced magnetic anisotropy		
Nickel ferrite	Royce [66R2]	II
Yttrium iron garnet, polycrystalline	Shaner and Royce [68S1]	II
Yttrium iron garnet, polycrystalline	Grady et al. [72G1]	IV
Nickel ferrite	Seay et al. [67S1]	III
48% Co 50% Fe 2 V (Supermendur)	present work	III

(a) Compositions are by atomic fraction or per cent.

(b) Methods refer to fig. 4.7. I is 4.7(a); II is 4.7(b); III is 4.7(c); IV is 4.7(d).

Except for a pronounced nonlinearity at low stresses, magnetization is observed to change smoothly with pressure in fcc alloys. An apparent non-linearity for small magnetizations is probably an artifact related to the sample configuration or the weak magnetic fields employed. In any event, as shown in table 4.7, the pressure derivatives obtained from steeply-rising regions of magnetization versus pressure data are in agreement with static measurements to about 10 per cent.

Table 4.7

Pressure derivatives of magnetization and Curie temperatures (compression is taken as positive)

Material	Static pressure	Shock compression	Reference
$\partial \ln M_s/\partial p$	% GPa^{-1}	% GPa^{-1}	
31.4% Ni 68.6% Fe	-32 to -37	-28 to -33	Wayne [69W1]
35% Ni 65% Fe	-14	-13	See Graham [68G3]
$Fe_{0.65}(Ni_{0.94}Co_{0.06})_{0.35}$	—	-13	Edwards [78E1]
$Fe_{0.65}(Ni_{0.92}Co_{0.08})_{0.35}$	—	-14	Edwards [78E1]
$\mathrm{d}T_c/\mathrm{d}p$	K GPa^{-1}	K GPa^{-1}	
28.4% Ni 61.6% Fe	-32 to -57	-58	See Graham et al. [67G2]
35% Ni 65% Fe	-34	—	Edwards and Bartel [74E1]
$Fe_{0.65}(Ni_{0.94}Co_{0.06})_{0.35}$	-39	—	Edwards and Bartel [74E1]
$Fe_{0.65}(Ni_{0.92}Co_{0.08})_{0.35}$	-41	—	Edwards and Bartel [74E1]

Shock-demagnetization measurements on alloys which undergo first-order polymorphic phase transitions show features quite different from those on fcc alloys. In this case, multiple waves propagate in the sample and their interaction after the reflection of the leading wave prevents the entire sample from being demagnetized. As a result, maximum output current is achieved only in pressure ranges in which the first wave is overdriven. Magnetization measurements reported for Silectron [68G3] were analyzed to account for that effect. The pressure of 40 GPa reported by Novikov and Mineev [74N3] to achieve maximum signal from shock-loaded iron composites apparently corresponds to the overdrive pressure. Kiselev's report of incomplete demagnetization of iron at 33 GPa may involve multiple wave effects due to imperfect impedance matching [75K1].

The pressures at which substantial shock demagnetization occurs indicates onset of transitions 14.5 GPa for the 6.3 per cent silicon alloy and 6.5 ± 0.5 GPa for the 28.4 atomic per cent nickel-iron alloy, which are in good agreement with independent determinations from wave profiles [63Z1, 70R1]. Sketchy data on a bcc 10 per cent Mn–Fe alloy indicate substantial demagnetization to have occurred at pressures from 12 to 27 GPa [78G1].

The picture that has emerged from investigations of shock demagnetization due to first- and second-order transitions is one in which response to shock loading corresponds well with static-high-pressure studies of pressure dependencies of magnetization or Curie temperature and with pressure-volume determinations of polymorphic first-order phase transitions under shock loading. Since the fcc iron alloys do not exhibit polymorphic phase transitions, shock demagnetization of most of these alloys is limited to Curie-point transitions occurring behind strong shocks.

Changes in magnetization and Curie temperature considered above are a manifestation of *volume* magnetostriction and are largely independent of shear stress. Materials with large *linear* (i.e., uniaxial) magnetostrictive constants exhibit an inverse effect called “stress-induced magnetic anisotropy” in which the magnetic behavior is determined by the magnitude and sign of the shear