As an example of a typical inductance calculation, consider a pipe magnetized to saturation following the path $-B_rH_cPQ$ and having $B_r = 1.2 \text{ T } (12 \text{ kG})$, $H = 2400 \text{ A} \cdot \text{m}^{-1} (30 \text{ Oe})$, $\ell = 10 \text{ m } (30 \text{ ft})$, P = 1.2 T (12 kG), R = 136.5 mm (5.25 in.) and T = 12.6 mm (0.5 in.). Here, dB is 2.3 T (23 kG), so that $dB \cdot (dH)^{-1}$ is 0.001 in SI (800 in CGS units) and L in SI units is:

(15)
$$L = 10 \text{ m} \frac{12 \text{ mm}}{2\pi \cdot 136.5 \text{ mm}} 0.001$$

= 139.9 uH

or in CGS units:

(16)
$$L = 2 \times 10^{-7} (10 \text{ m}) (12 \text{ mm}) \frac{800}{136 \text{ mm}}$$

= 141 \(\mu \text{H} \)

Using the same tube as above, a path is taken from Q through P and B_s to B_r by a second pulse, with $B_s = 1.5$ T (15 kG), $dH = 4000 \text{ A} \cdot \text{m}^{-1}$ (50 Oe) and Q = 1.0 T (10 kG).

The average value of $dB \cdot (dH)^{-1}$ is then only $1 \div 8000$, 1.25×10^{-4} , in the SI system or 100 in the CGS system. Dividing the original inductance value by 8 (the ratio of the two $dB \cdot (dH)^{-1}$ values exhibited by the steel) yields $L = 18.5 \, \mu\text{H}$.

As another example, consider an unmagnetized pipe that follows a path O,P, B_s , B_t , where $B_s = 1.5$ T (15 kG); $dH = 3200 \text{ A} \cdot \text{m}^{-1}$ (40 Oe); $\ell = 28$ mm (1.1 in.); P = 9.1 m (30 ft); T = 4.8 mm (0.2 in.).

The inductance value is calculated in the SI system as:

(17)
$$L = 9.1 \text{ m} \left(\frac{4.8 \text{ mm}}{2\pi \cdot 28 \text{ mm}} \right) \frac{1.5 \text{ mm}}{3200}$$

= 116 \text{ \text{µH}}

or in CGS as:

(18)
$$L = 2 \times 10^{-7} (9.1 \,\mathrm{m}) (4.8 \,\mathrm{mm}) \frac{15000}{28 \,\mathrm{mm}}$$

= 119 \(\mu \text{H} \)

The relatively large change in inductance exhibited by the tube in the two examples affects the shape of the pulse waveform, notably the easily measurable parameters of peak current $I_{\rm max}$ and pulse duration (Fig. 17).

Design Considerations

Good equipment design must consider the material being magnetized. The worst internal and external resistances of the magnetizing system should be known to the manufacturer and corresponding inductance values should be investigated. Under no circumstances should peak currents be stated for magnetization without an electrical and magnetic load for system evaluation.

Depending on the use of the equipment, regulations should be consulted with regard to insulation, isolation, explosion proofing, intrinsic safety and purging. Such regulations are available from many sources, depending on the use of the product. Notable among these, in the United States, are the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). Various international standards are considerably more stringent than those in the United States. Equipment designers should particularly note the requirements of the United Kingdom, Norway and Germany when designing for North Sea applications. The Canadian Standards Administration should be consulted when designing for applications in Canada.

Magnetization Recommendations

Tubular products vary between such wide limits of diameter and wall thickness that it is difficult to provide a universal specification for the measurable parameters of current pulses for high residual induction. However, the values in Table 4 are based on research with a variety of tubes and can serve as broad guidelines to ensure adequate magnetization.²⁶

As tabulated, the pulses are classified into long, moderate and short duration. Long duration pulses are those in excess of 100 ms (Fig. 23). For such pulses, the induced eddy current is assumed to have dissipated while the magnetizing field intensity is still high enough to cause saturation.

Moderate pulses are those with durations between 40 and 100 ms (Fig. 23). For magnetization, the longevity

TABLE 4. Generalized current duration requirements for adequate magnetization of tubes.

Duration (ms)	Current Re	quirement Old Unitsb
>100	I _ 11 9 D	I = 300·D₂
		$I = 300 \cdot D_2$ $I = 110 \cdot W_2$
0 to 40	$I = 161 \cdot W_1$	$I = 240 \cdot W_2$
0 to 40	$I = 121 \cdot W_1$	$I = 180 \cdot W_2$
0 to 40	$I = 97 \cdot W_1$	$I= 145 \cdot W_2$
	>100 40 to 100 0 to 40 0 to 40	(ms)SI Unitsa>100 $I = 11.8 \cdot D_1$ 40 to 100 $I = 74 \cdot W_1$ 0 to 40 $I = 161 \cdot W_1$ 0 to 40 $I = 121 \cdot W_1$

a. D_1 is outside diameter (mm); W_1 is tube weight (kg·m⁻¹). b. D_2 is outside diameter (in.); W_2 is tube weight (lb·ft⁻¹).