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EG&G INC.

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PREDICTED CAPABILITIES OF THE EG&G SIMULATION LABORATORY 100 KILOJOULE CAPACITOR BANK

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Prepared for
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SYSTEMS DIVISION

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SECTION 1
GENERAL CAPACITOR BANK CHARACTERISTICS

A relatively fast, high-energy capacitor bank with extremely low inductance is currently being fabricated for EG&G by Maxwell Laboratories, Inc. of San Diego, California. It will serve as the pulse power supply for both the magnetic impulsive loading and sheet HE initiation programs. The bank output terminates in horizontal flat-plate transmission lines, and is characterized by the following nominal design parameters.

V_o, Maximum rated charging voltage = 50 kilovolts

E_o, Maximum stored capacitive energy = 100 kilojoules

C, Rated bank capacitance = 80 microfarads

L_B, Total bank inductance including inductance of switch and flat-plate transmission lines ~ 3 nanohenries

f_o, Short-circuit ringing frequency ~ 332 kilohertz

R_o, Total internal bank ac resistance ~ 0.8 milliohms

I_o^{max}, Maximum short-circuit current ~ 7.5 megamperes

τ_o, Short-circuit full-cycle period ~ 3.0 microseconds

The 100-kilojoule capacitor bank is the property of the Sandia Corporation, sponsors of several experimental impulsive loading programs being conducted by EG&G. The bank will be installed and operated at the EG&G Simulation Laboratory in Bedford, Massachusetts. The predicted capabilities of the bank when employed as an impulsive load generator are described in this report.

2.1 UNIFORM RADIAL LOADING OF CYLINDRICAL SAMPLES

A cylindrical test sample can be uniformly loaded over its curved surface by utilizing a single-turn load coil with a matching curved flyer plate that are separated by an insulator of thickness Δ. The flyer plate conforms to the contour of the test specimen. The load coil assembly is solenoidally affixed to the bank transmission lines, so that the current flow through the coil and flyer plate is in the tangential direction. The magnetic fields produced by such currents are in the axial direction as can easily be determined by the Biot-Savart Law or by application of the "right-hand" rule. The resultant magnetic forces of repulsion will therefore drive the flyer plate radially inward.

The relationship between the current and the corresponding magnetic field is given by the long solenoid approximation

$$B = 0.4\pi \frac{I}{\ell} \quad \text{Gauss,} \tag{1}$$

where I is the current, in amperes, and ℓ the axial length of the solenoidal load assembly, in centimeters.

One can show from conservation of energy considerations that the load inductance in this configuration is given by (Reference 1)

$$L = 4\pi \frac{A}{\ell} \quad \text{nanohenries} \tag{2}$$

where A is the area, in square centimeters, of the insulation spacing between the coil and flyer plate.

As the flyer plate is accelerated from the load coil the insulation spacing Δ varies with time. Thus, the load inductance is a time-varying quantity and is given explicitly by the relationship (Reference 1)

$$L(t) = \frac{4\pi^2}{\ell}\left(R_c^2 - R_f^2(t)\right) \quad , \tag{3}$$

where R_c and $R_f(t)$ are the inner radius of the coil and the time-varying position of the outer edge of the flyer plate in centimeters.

A semi-circular load assembly can be used to uniformly load a test cylinder over segments of arc up to 180 degrees. Since R_c and R_f are nearly equal and are related by

$$R_c = R_f + \Delta \ , \tag{4}$$

the inductance of such a load assembly is given to good approximation by

$$L(t) \sim \frac{4\pi^2}{\ell} R_f(o)\ \Delta(t) \quad , \tag{5}$$

where $R_f(o)$ is the initial position of the flyer plate.

As an example, consider a test specimen 12 inches in diameter and 18 inches long. Choosing 0.030 inch of mylar insulation to withstand voltages up to 25 kilovolts between the load coil and flyer plate, one obtains from Equation (5) a value for the initial load inductance of

$$L(o) = 1 \text{ nH}$$

where $\Delta(o) = 7.62 \times 10^{-2}$ cm,

$\ell = 45.72$ cm,

and $R_f = 15.24$ cm.

If the flyer plate and test specimen are placed with an initial separation of $\Delta(o) = 0.060$ inch, the load inductance will have trebled its initial value when the flyer plate has traversed the distance $\Delta(o)$ and struck the test cylinder. The total circuit inductance, comprising the sum of the bank and load inductances, will therefore vary from 4 nanohenries to 6 nanohenries during the course of the flyer plate motion.

The exact solution for such a time-varying LRC circuit involves mathematical complexities which exceed the scope of this report. One can obtain an approximate solution adequately describing the physics of the problem by assuming that over the times of interest, the load presents an effective average inductance, $\overline{L}$, of 2 nanohenries to the capacitor bank. Using this approximation, the now constant LRC circuit has a total inductance of

$$L_T = L_B + \overline{L} = 5 \quad \text{nH} \tag{6}$$

Thus, the 100-kilojoule capacitor bank operated in an underdamped condition will have a ringing frequency of

$$f = \frac{1}{2\pi} \sqrt{\frac{1}{CL_T}} \sim 252 \quad \text{kHz} \tag{7}$$

An electromagnetic wave entering a conductor of finite conductivity exhibits an exponential damping with distance. This damping is characterized by the penetration depth δ which is a function of both the wave frequency and the electromagnetic properties of the conductor, and is given explicitly by (Reference 2)

$$\delta = \left(\frac{1}{\mu\sigma\pi f}\right)^{1/2} \quad \text{meters} \tag{8}$$

where μ and σ are, respectively, the magnetic permeability and electrical conductivity of the flyer plate material in rationalized MKS units.

The flyer plates are at present fashioned from dead-soft 1100 aluminum for which

$$\mu = 4\pi \times 10^{-7} \quad \text{webers/amp-meter}$$

$$\sigma = 3.51 \times 10^{7} \quad \text{mho/meter}$$

and thus the penetration depth $\delta = 0.166$ millimeter at 252 kHz.

The optimum thickness of the flyer plate is dictated by the value of the penetration depth. When a damped sinusoidal magnetic field is applied to the surface of a conductor of finite thickness, h, the flux lines diffuse into the conductor at a rate determined by the penetration depth in the conducting medium and both the angular frequency and damping rate of the applied field (Reference 3). Let $B_d(h, t)$ denote the magnetic field that penetrates to the inner surface of a flyer plate of thickness h in time t. Similarly, let $B_s(o, t)$ denote the field that is produced at the outer surface by the discharge of the capacitor bank. This outer surface field is given explicitly by

$$B_s(o, t) = 0.4\pi \frac{V_o \omega C}{\ell} e^{-at} \sin \omega t \tag{9}$$

where $\omega = 2\pi f$ is the angular frequency

and $a = R/2L_T$ is the damping rate of the RLC circuit.

The behavior of the diffusion field, $B_d(h, t)$ is given by complementary error functions of complex argument. The diffusion field is also proportional to the quantity $\frac{V_o \omega C}{\ell}$.

The net magnetic flux which acts on the flyer plate, and therefore contributes to the magnetic pressure, is given by the difference $B_s - B_d$.

The design of the load coil is such that its thickness is many penetration depths. One can assume that all the magnetic flux produced at the load coil by the currents in the flyer plate contributes to the magnetic pressure which is then given by

$$P_M = \frac{B_s (B_s - B_d)}{8\pi} \quad \frac{\text{dyne}}{\text{cm}^2} \qquad (10)$$

One can observe from this last result together with the above remarks that the magnetic pressure varies as the inverse square of the axial length, ℓ.

This magnetic pressure produces a given acceleration for a given flyer plate thickness. As the flyer plate thickness is decreased, the mass per unit area which must be accelerated is correspondingly diminished, but conversely, the increased diffusion of the magnetic field through the thinner flyer plate reduces the available magnetic pressure. One finds that maximum acceleration can be achieved with a flyer plate thickness between 0.65 δ and 1.2 δ, where δ is the penetration depth. For the present case, the optimum flyer plate thickness lies between 4 and 8 mils.

A computer program has been devised to calculate the flyer plate velocity as a function of time. The required input information includes

angular ringing frequency, ω, in $\sec^{-1}$

damping rate, a, in $\sec^{-1}$

bank capacitance, C, in farads

charging voltage, V_o, in volts

flyer plate thickness, h, in meters

flyer plate axial length, ℓ, in centimeters initial separation between flyer plate and test sample, d_o, in centimeters

flyer plate density, ρ, in gm/cm^3

flyer plate conductivity, σ, in mho/m

and flyer plate permeability, μ, in webers/amp-meter

The load coil together with a flyer plate 4 mils in thickness constitute an ac load resistance of 0.3 milliohm at 252 kHz. The total circuit resistance (the sum of the bank and load resistances) is therefore approximately 1.1 milliohms which produces a circuit damping rate of 1.1×10^5 sec^{-1}.

Thus for

$$\omega = 2\pi f = 1.58 \times 10^6 \text{ sec}^{-1}$$
$$a = 1.10 \times 10^5 \text{ sec}^{-1}$$
$$C = 8.0 \times 10^{-5} \text{ F}$$
$$V_o = 5.0 \times 10^4 \text{ volts}$$
$$h = 1.02 \times 10^{-4} \text{ meter}$$
$$\ell = 45.72 \text{ cm}$$
$$d_o = 0.152 \text{ cm}$$
$$\rho = 2.71 \text{ gm/cm}^3$$
$$\sigma = 3.51 \times 10^7 \text{ mho/m}$$
$$\mu = 4\pi \times 10^{-7} \text{ weber/amp-meter}$$

One obtains a value of 0.383 millimeter per microsecond for the flyer plate velocity just prior to impact. The flyer plate will require approximately 6.5 microseconds to traverse the initial separation distance and will impact the test sample with a kinetic energy of 4.4 kilojoules, producing an impact pressure of nearly 28 kilobars in an aluminum target, with a pulse duration of 38 nanoseconds.

One can readily calculate the efficiency of the system in doing work on the flyer plate. A maximum current of 5.7 megamperes is produced in the circuit, resulting in a maximum energy of $E_{max} = \frac{1}{2} \overline{L} I_{max}^2 = 32.4$ kilojoules being stored in the magnetic field of the load inductance. The flyer plate has a kinetic energy of 4.4 kilojoules upon impact. Therefore, the operating efficiency of the system is

$$\eta = \frac{E_f}{E_{max}} = 0.14 \qquad (11)$$

Previous experience has shown that the flyer plate velocities and transit times calculated in this manner agree within ±5 percent with empirical values obtained from streak photograph records and pin-closure measurements.

As one varies the flyer plate thickness while maintaining the identical load configuration, the circuit parameters remain basically unchanged, but the variation in the magnetic diffusion produces changes in the magnetic pressure which in turn affects the flyer velocity profile. Flyer plate velocities and transit times as a function of flyer thickness are shown in Table 1.

Note that flyer plates having thicknesses between 4 and 8 mils are accelerated to the maximum velocity, but that an 8-mil flyer has the greatest kinetic energy upon impact. For flyer plate thicknesses less than two penetration depths, the flyer momentum density increases markedly with increasing thickness because of the magnetic diffusion.

TABLE 1. VELOCITY OF AN 18-INCH SOLENOID FLYER PLATE AS A FUNCTION OF THICKNESS (for Δ = 30 mils)

h (mils)	v_f $\frac{mm}{\mu sec}$	t_a (μsec)*	Γ (taps)**	E_f (kj)	η
4	0.383	6.5	1050	4.4	0.14
6	0.368	6.9	1520	6.1	0.19
8	0.346	7.4	1910	7.2	0.22
12	0.279	8.6	2300	7.0	0.22
16	0.230	10.0	2530	6.4	0.20
20	0.191	11.7	2630	5.5	0.17
32	0.120	16.8	2650	3.5	0.11

*t_a = transit time of flyer plate
**Γ = flyer plate momentum density at impact

When the flyer plate thickness exceeds twice the penetration depth magnetic diffusion is not a major factor.

The operating efficiency can be moderately increased simply by decreasing the insulation thickness between the load coil and the flyer plate. If Δ is reduced from 30 mils to half that value (15 mils of mylar is still sufficient to withstand 20 kilovolts), the average load inductance is reduced from 2 nanohenries to 1.5 nanohenries. This in turn raises the bank ringing frequency from 252 kilohertz to 265 kilohertz and serves to increase the maximum velocity that can be achieved by the flyer plate. These points are illustrated by comparing the values in Table 2 with the corresponding entries in Table 1.

TABLE 2. VELOCITY OF AN 18-INCH SOLENOID FLYER PLATE AS A FUNCTION OF THICKNESS (for $\Delta = 15$ mils)

h (mils)	v_f $\frac{\text{mm}}{\mu\text{sec}}$	t_a (μsec)	Γ (taps)	E_f (kj)	η
4	0.410	6.0	1130	5.0	0.18
6	0.393	6.4	1620	6.9	0.26
8	0.370	6.9	2040	8.2	0.31
12	0.296	8.1	2450	7.9	0.29
16	0.244	9.5	2690	7.1	0.26
20	0.202	11.1	2790	6.1	0.23
32	0.128	15.9	2820	4.0	0.15

The flyer plate is designed so that the current will flow uniformly over its entire surface. If care is taken to position the entire flyer plate a uniform distance d_o from the test sample, the loading should be simultaneous over any desired region of the test sample. In actual experiments, this separation distance can vary by 5 mils, thus producing a non-simultaneity in the arrival time of 0.3 microsecond or 5 percent for the 4-mil flyer plate.

The duration of the impact pressure pulse is governed by the local sound speed in the flyer material. The impact pressure delivered to a test sample by a flyer plate having a velocity v_f at impact is well approximated by a square pulse of magnitude

$$P = \frac{Z_t \, v_f}{1 + \frac{Z_t}{Z_f}} \qquad (12)$$

where Z_f and Z_t are the mechanical impedances, in gm-sec per square centimeter of the flyer and target materials.

The pulse duration is

$$\tau = 2\frac{h}{C_f} = \frac{2\rho h}{Z_f} \tag{13}$$

where C_f is the local sound speed in the flyer material.

One can derive Equation (12) by applying the principle of conservation of linear momentum to the flyer-target impact phenomenon. If the flyer plate and target materials are identical, the flyer plate will come to rest after impact and all the momentum contained in the flyer plate, will be transferred to the target. If the mechanical impedance of the target material is greater than that of the flyer plate, the latter will rebound upon impact. The momentum transferred to the target will thus exceed the flyer plate momentum by an amount equal to the rebound momentum. The impact pressure will correspondingly be greater than that produced for the case of identical flyer and target materials. Conversely, the case of $Z_f > Z_t$ results in the flyer plate remaining attached to the target material after impact with a corresponding decrease in the momentum transferred and the impact pressure transmitted. Impact pressures incident on various test materials, which include each of the three situations mentioned above, are listed in Table 3 as a function of flyer plate thickness. A plot of maximum impact pressure versus pulse duration for an aluminum test specimen is shown in Figure 1. The region to the left of the solid line defines the operating range of the capacitor bank in this particular experimental configuration. All combinations of pressures and pulse durations in this operating range are within the capability of the bank. Similar P, τ plots illustrating the operating ranges for beryllium, steel, and teflon test specimens are illustrated in Figures 2, 3, and 4 respectively. A single plot of the four operating curves is shown in Figure 5.

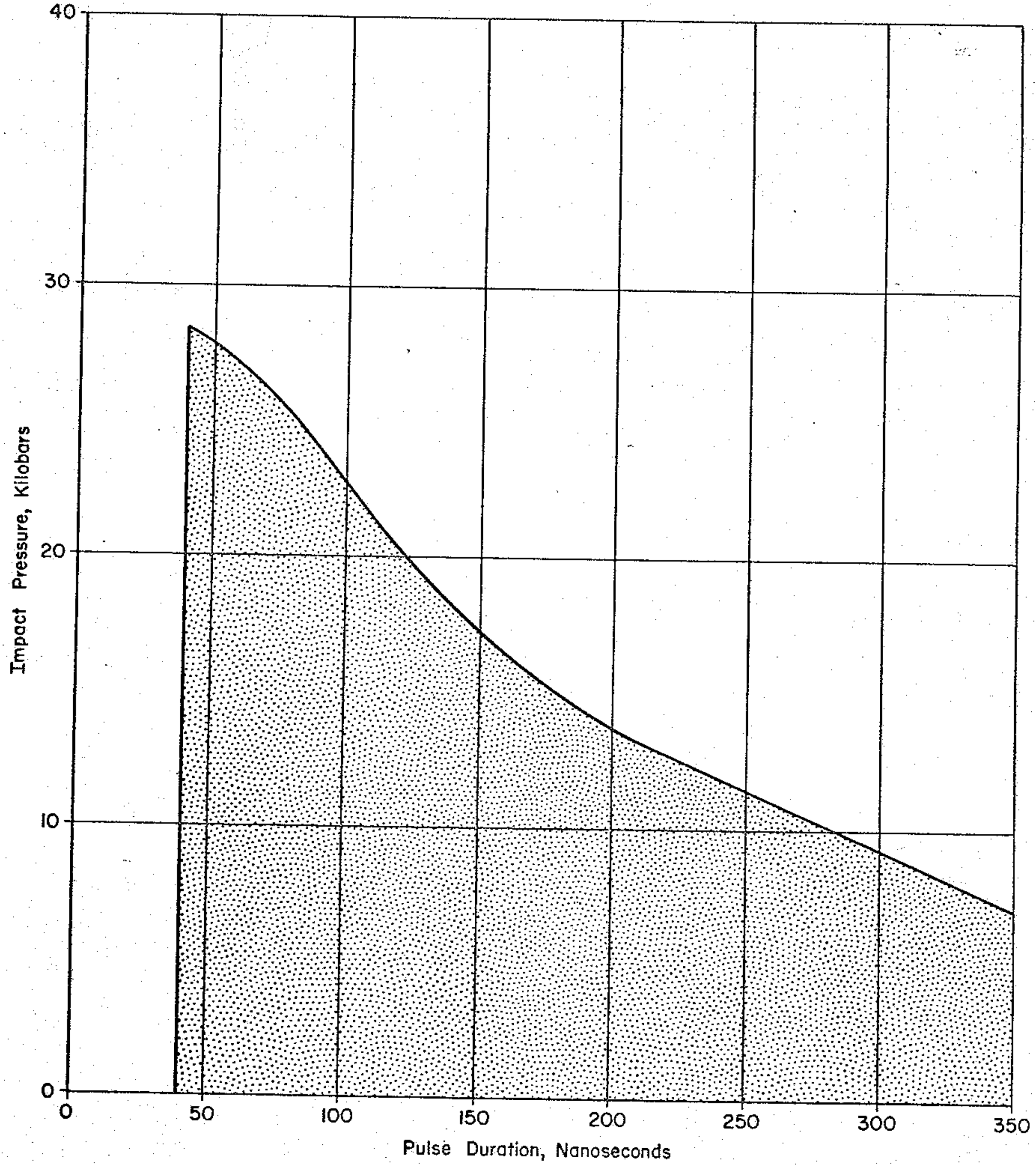

Figure 1. Operating range for 12-inch diameter, 18-inch long aluminum test specimens.

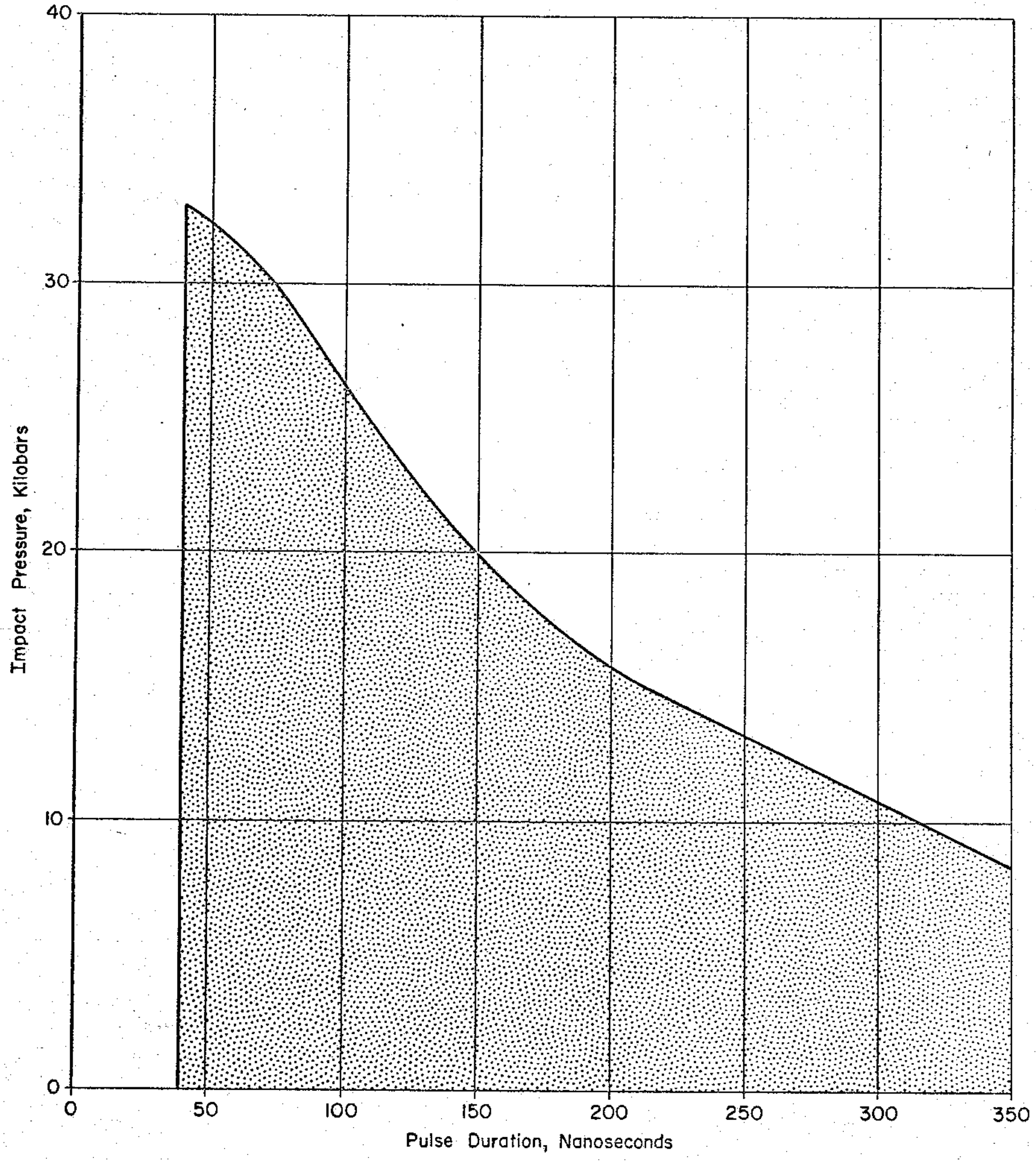

Figure 2. Operating range for 12-inch diameter, 18-inch long beryllium test specimens.

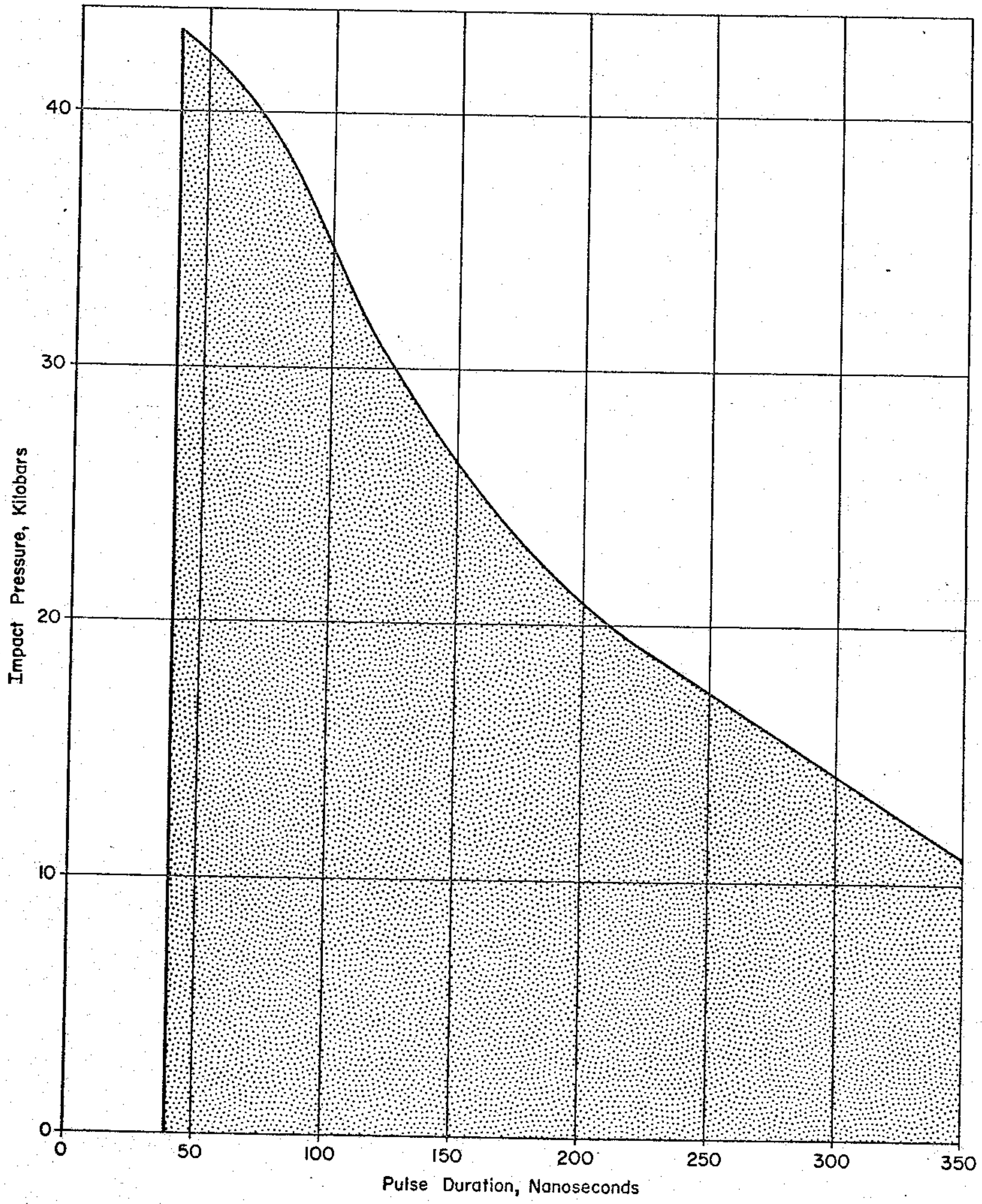

Figure 3. Operating range for 12-inch diameter, 18-inch long steel test specimens.

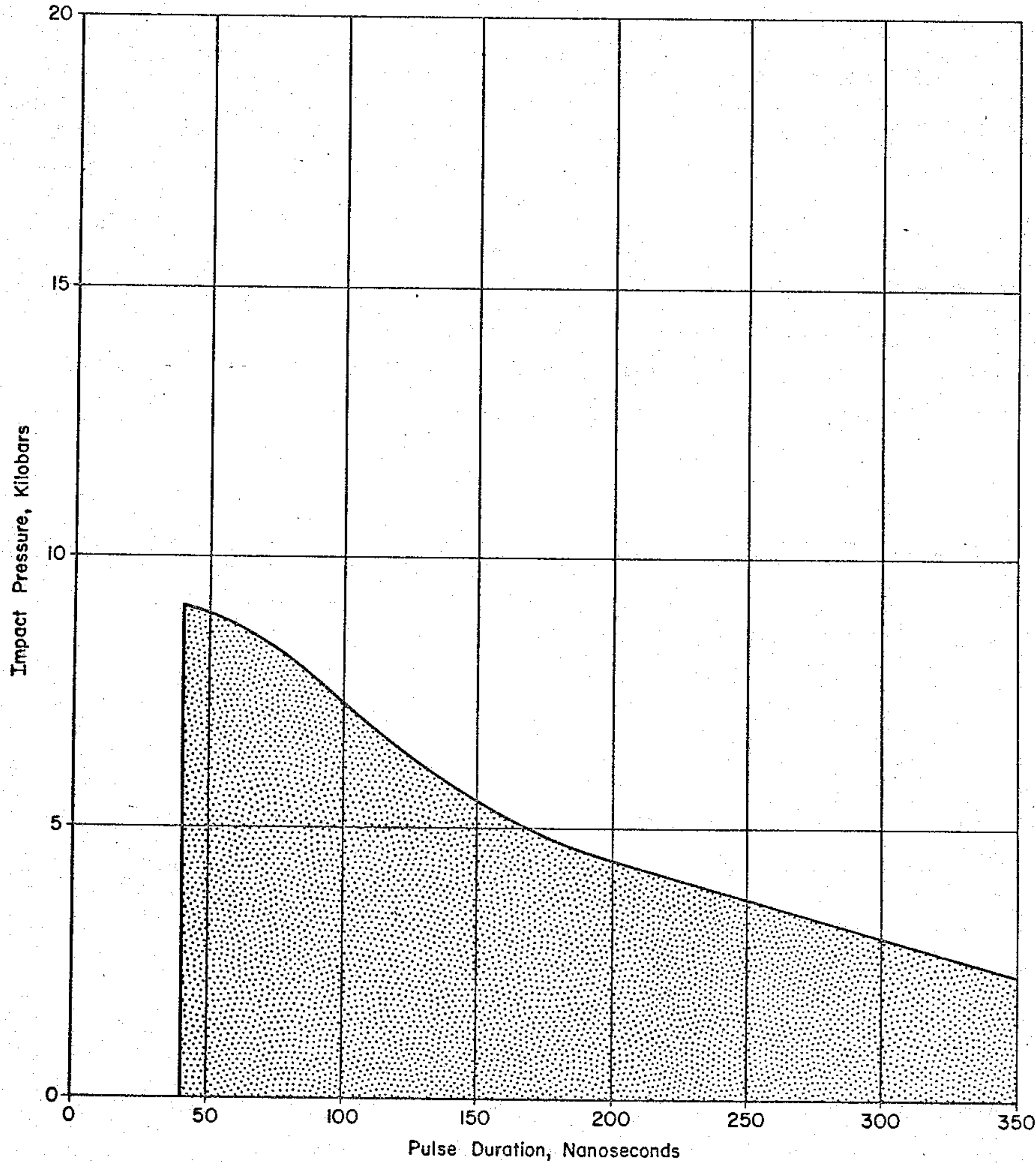

Figure 4. Operating range for 12-inch diameter, 18-inch long aluminum test specimens.

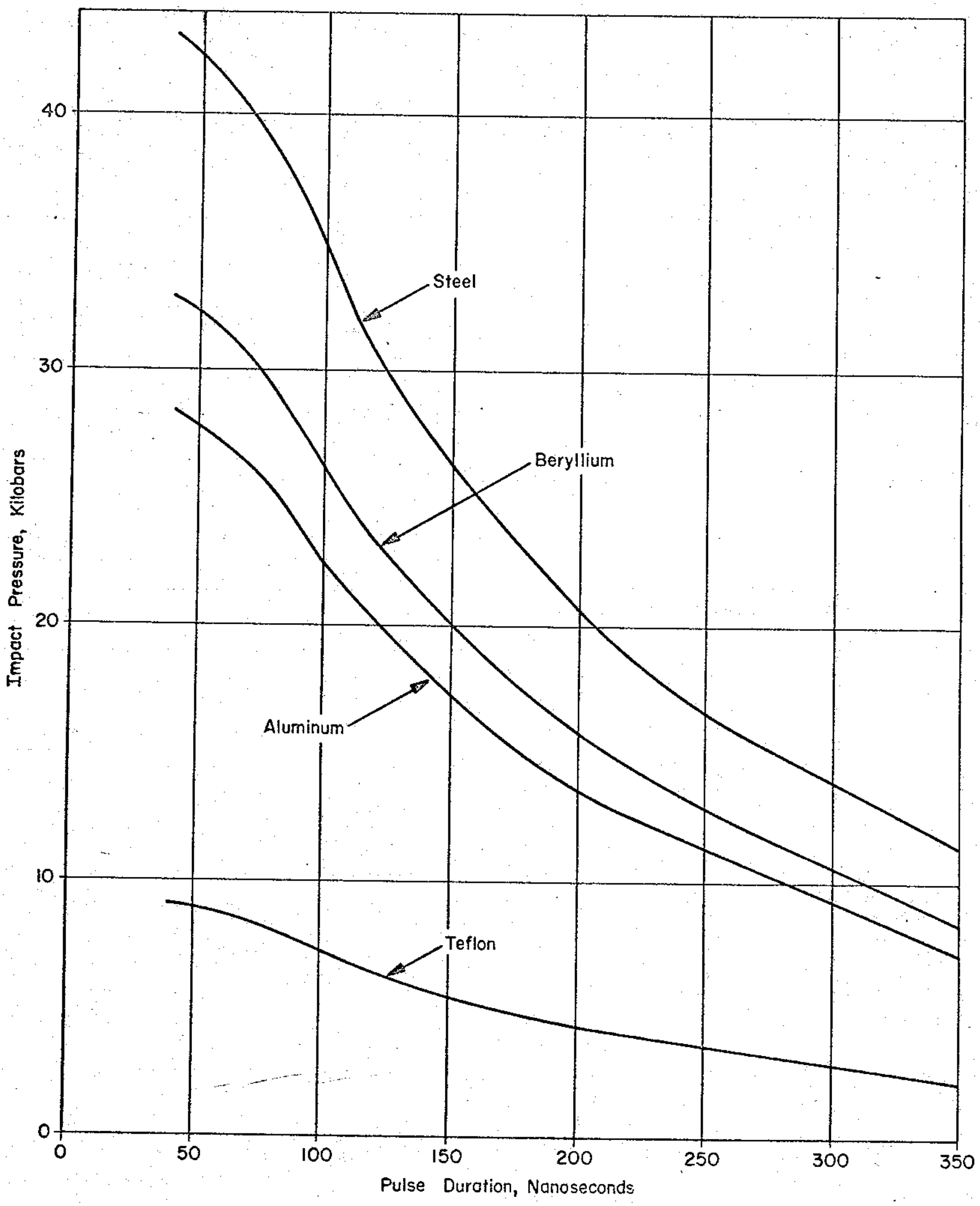

Figure 5. Operating curves for several different 12-inch diameter, 18-inch long test specimens.

TABLE 3. FRONT SURFACE IMPACT PRESSURE AS A FUNCTION OF 18-INCH LONG FLYER PLATE THICKNESS FOR VARIOUS TARGET MATERIALS

h (mils)	τ (ns)	Incident Impact Pressure (kilobars)			
		Aluminum	Beryllium	Steel	Teflon
4	39	28.3	32.8	43.1	9.1
6	59	27.1	31.4	41.3	8.7
8	78	25.5	29.6	38.9	8.2
12	117	20.4	23.7	31.1	6.6
16	156	16.8	19.5	25.6	5.4
20	195	13.9	16.2	21.2	4.5
32	312	8.8	10.2	13.4	2.8

2.2 AXIAL CURRENT FLOW CONFIGURATION

As can be seen from Equations (5) and (10) the magnetic pressure impulse is nearly inversely proportional to the square of the axial length. The maximum flyer plate velocity that can be achieved with the 100-kilojoule bank and the load configuration described above, will greatly diminish if the length of the flyer is increased above 18 inches. For example, a 12-mil flyer plate 18 inches long can reach a velocity at impact of 0.30 millimeter per microsecond whereas a similar cylindrical curved flyer of identical thickness and radius of but twice the length can be accelerated to a final velocity of only 0.10 millimeter per microsecond.

It is therefore advisable, for lengths in excess of 18 inches, to change the load configuration and attachment such that the current flow in the load coil and flyer plate is axial rather than solenoidal. The resulting magnetic fields will then be in the theta or tangential direction and will now be limited by the diameter of the cylinder rather than by its length. The magnetic pressure will again be directed radially inward.

The expressions for the load inductance and the magnetic pressure will be analogous to those derived earlier, with the rules of the quantities ℓ and πR_f interchanged. Thus,

$$L(o) = 4 \frac{\ell \Delta}{R_f} \quad \text{nanohenries} \tag{14}$$

and

$$B_s = \frac{0.4\, V_o\, \omega C}{R_f} e^{-at} \sin \omega t \quad \text{Gauss} \tag{15}$$

For the same diameter cylinder as above, choosing ℓ = 36 inches, one finds L(o) = 0.9 nanohenry, $\overline{L}$ = 2.7 nanohenries, and the bank operating frequency is f = 230 kilohertz.

The flyer velocities that can be achieved in this instance are listed in Table 3. Note that the 12-mil flyer plate in an axial load configuration can be accelerated to an impact velocity of 0.23 millimeter per microsecond, whereas a final velocity of only 0.1 millimeter per microsecond can be achieved when the load coil is affixed solenoidally.

Impact pressures incident on 36-inch long aluminum, beryllium and steel test specimens are listed in Table 5 as a function of flyer plate thickness, while the appropriate P, τ curves illustrating the operating range for each material are shown in Figures 6 through 8.

With the current flow in the axial direction, a given increase in axial length produces a relatively small decrease in magnetic pressure. For a flyer plate 54 inches in length, one finds L(o) = 1.3 nanohenries, $\overline{L}$ = 4 nanohenries, and the bank operating frequency is 205 kilohertz.

The flyer velocities that can be achieved in this instance are listed in Table 6.

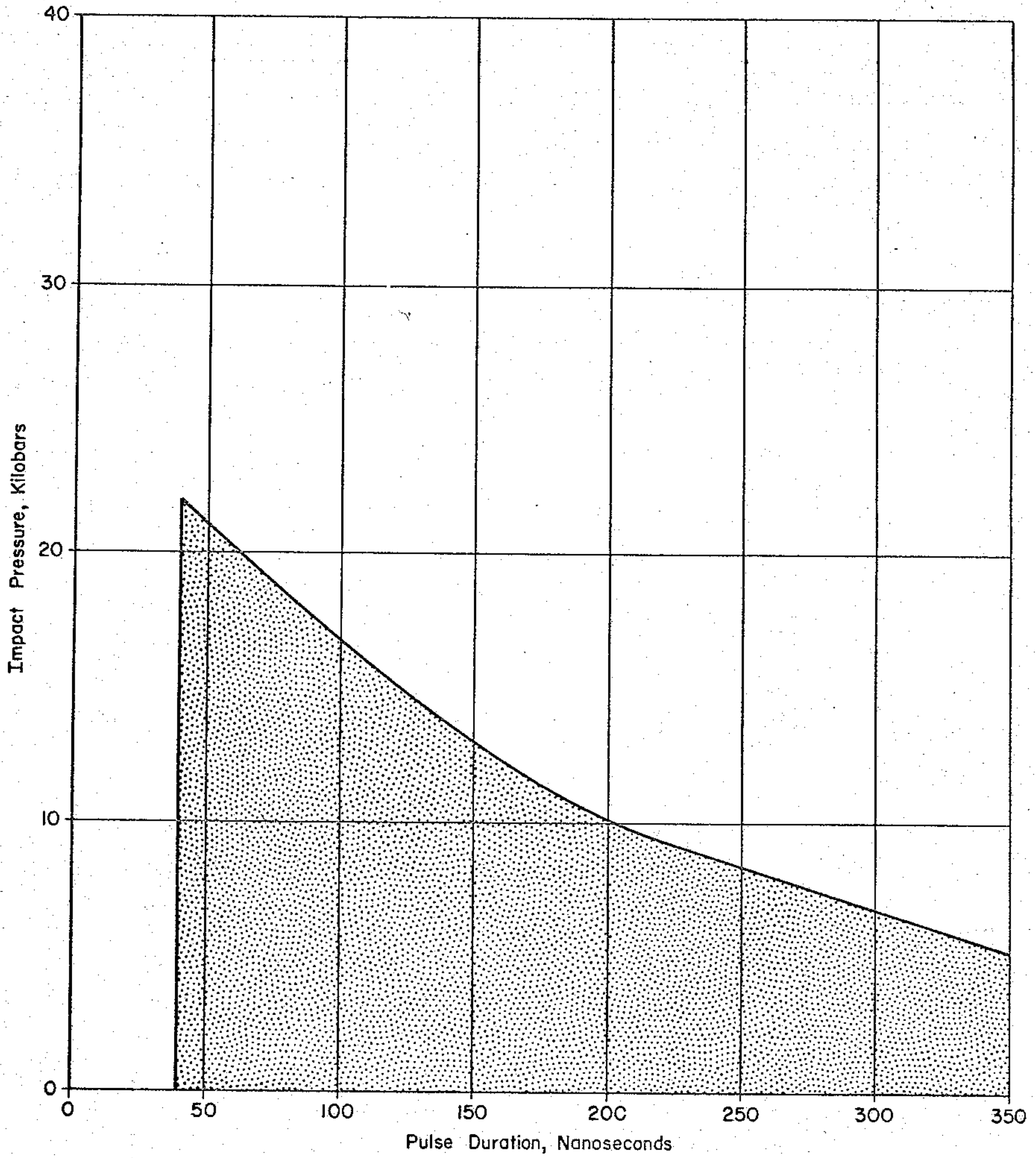

Figure 6. Operating range for 12-inch diameter, 36-inch long aluminum test specimens.

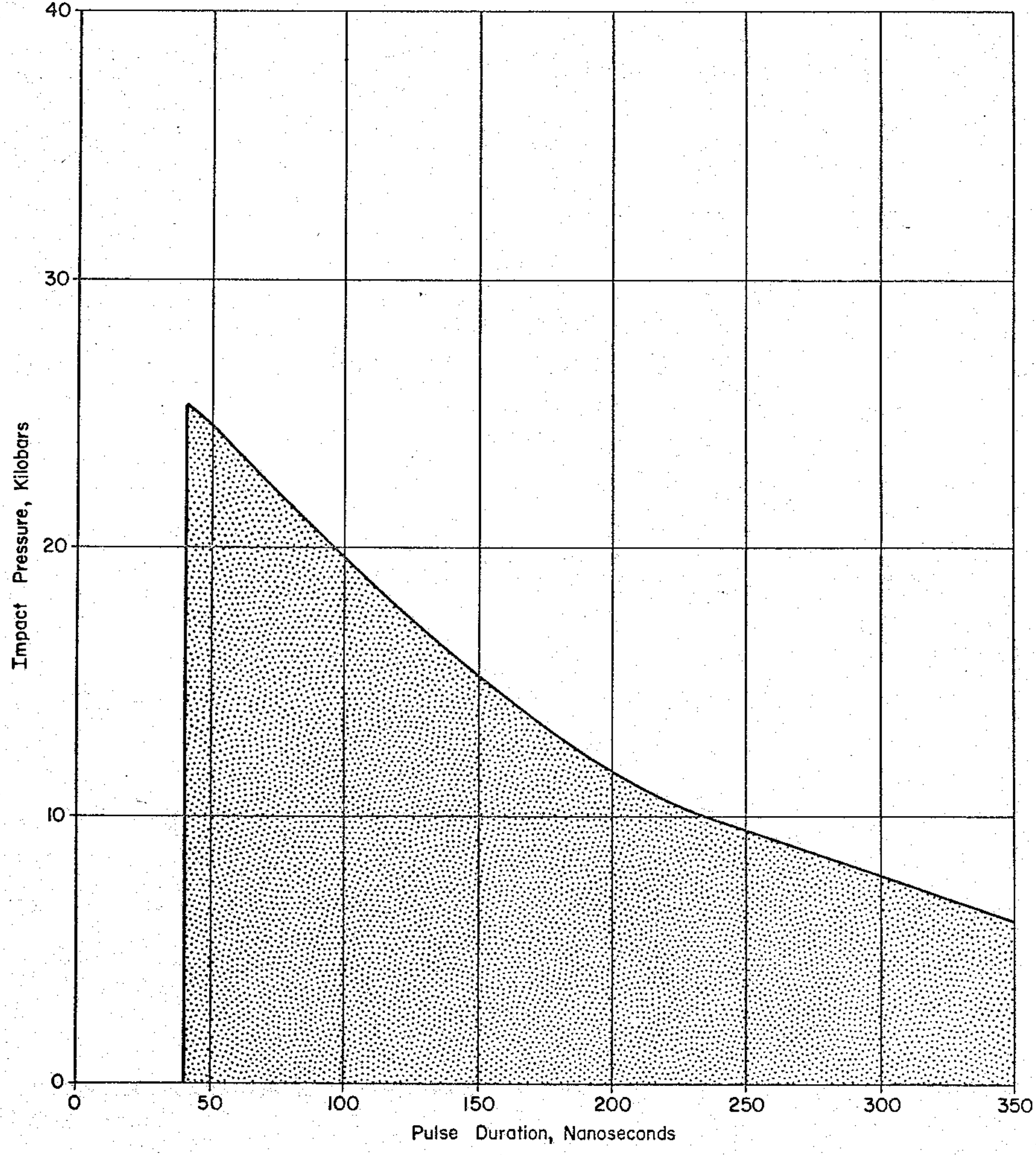

Figure 7. Operating range for 12-inch diameter, 36-inch long beryllium test specimens.

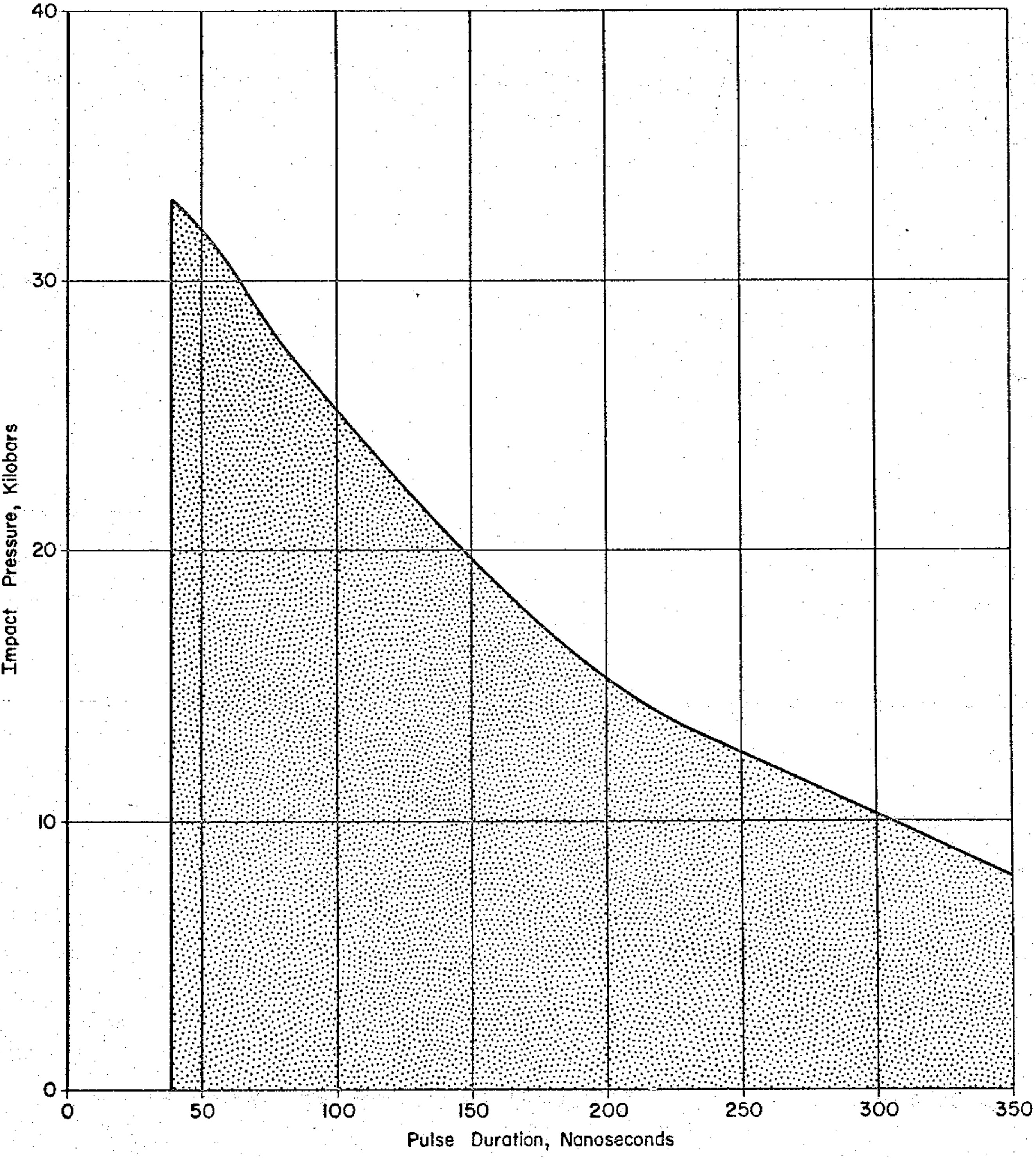

Figure 8. Operating range for 12-inch diameter, 36-inch long steel test specimens.

TABLE 4. VELOCITY OF 36-INCH LONG FLYER PLATE AS A FUNCTION OF FLYER PLATE THICKNESS (axial current flow)

h (mils)	v_f $\frac{mm}{\mu sec}$	t_a (μsec)	Γ (taps)	E_f (kj)	η_f
4	0.317	7.8	870	3.0	0.08
6	0.295	8.3	1220	3.9	0.10
8	0.267	8.9	1470	4.3	0.11
12	0.226	10.3	1860	4.6	0.12
16	0.183	12.1	2020	4.0	0.10
20	0.150	14.2	2060	3.4	0.09
32	0.093	20.7	2070	2.1	0.05

TABLE 5. FRONT SURFACE IMPACT PRESSURE AS A FUNCTION OF FLYER PLATE THICKNESS FOR VARIOUS TARGET MATERIALS (for 36-inch long specimens)

h (mils)	τ (ns)	Incident Impact Pressure (kilobars)		
		Aluminum	Beryllium	Steel
4	39	21.9	25.4	33.0
6	59	20.4	23.6	30.7
8	78	18.4	21.4	27.8
12	117	15.6	18.1	23.5
16	156	12.6	14.6	19.0
20	195	10.4	12.0	15.6
32	312	6.4	7.4	9.7

TABLE 6. VELOCITY OF 54-INCH LONG FLYER PLATE AS A FUNCTION OF THICKNESS (axial current flow)

h (mils)	v_f $\frac{mm}{\mu sec}$	t_a (μsec)	Γ (taps)	E_f (kj)	η_f
4	0.242	9.6	667	3.5	0.08
6	0.225	10.1	928	4.6	0.10
8	0.210	10.8	1150	5.3	0.12
12	0.174	12.5	1430	5.4	0.12
16	0.143	14.7	1570	4.9	0.11
20	0.117	17.2	1610	4.1	0.09
32	0.071	25.7	1570	2.4	0.05

Impact pressures incident on 54-inch long aluminum beryllium, and steel test specimens are listed in Table 7 as a function of flyer plate thickness, and the appropriate P, τ curves illustrating the operating range for each material are shown in Figures 9 through 11 respectively.

One should note by comparing corresponding entries in Tables 4 and 6, that for axial current flow, increasing the axial length from 36 to 54 inches produces only small changes in the flyer velocities and associated parameters.

One should also note that the operating efficiencies for the long-length axial-flow configurations are much lower than those that can be achieved for the relatively short-length solenoidal-flow case.

TABLE 7. FRONT SURFACE IMPACT PRESSURE AS A FUNCTION OF FLYER PLATE THICKNESS FOR VARIOUS TARGET MATERIALS (for 54-inch long specimens)

h (mils)	τ (ns)	Incident Impact Pressure (kilobars)		
		Aluminum	Beryllium	Steel
4	39	16.7	19.4	25.2
6	59	15.5	18.0	23.4
8	78	14.5	16.8	21.8
12	117	12.0	13.9	18.1
16	156	9.9	11.4	14.9
20	195	8.1	9.4	12.2
32	312	4.9	5.7	7.4

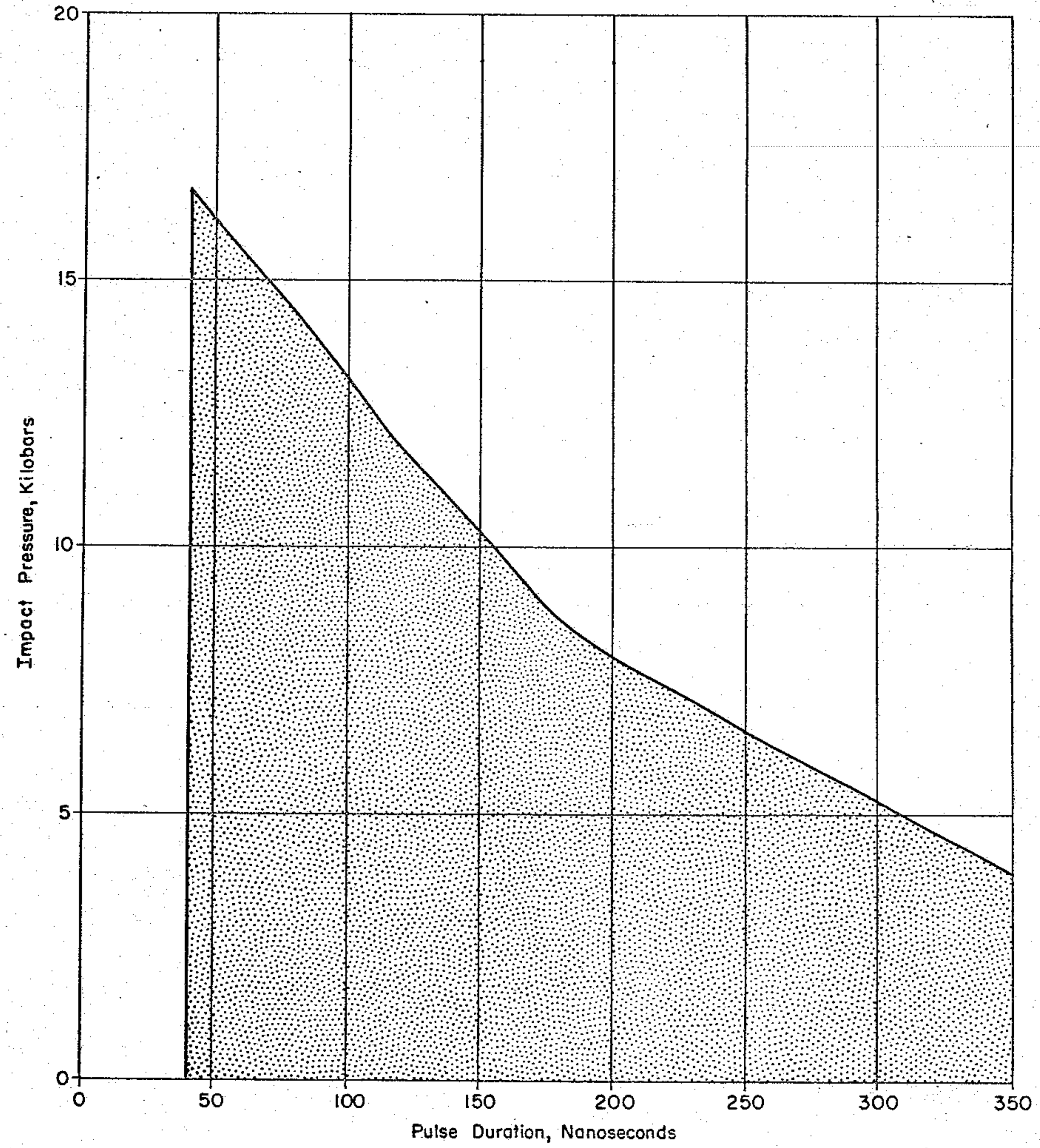

Figure 9. Operating range for 12-inch diameter, 54-inch long, aluminum test specimens.

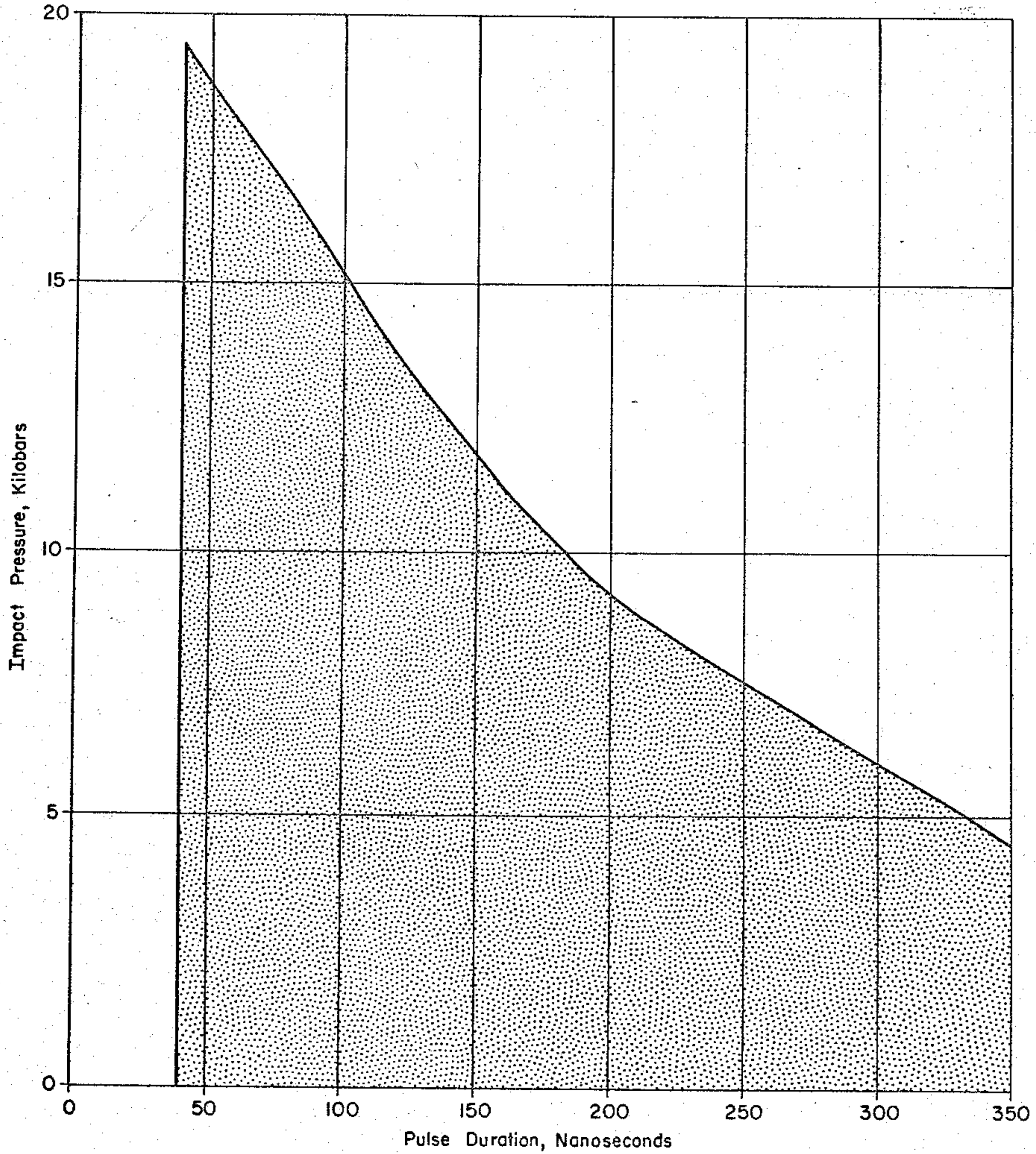

Figure 10. Operating range for 12-inch diameter, 54-inch long beryllium test specimens.

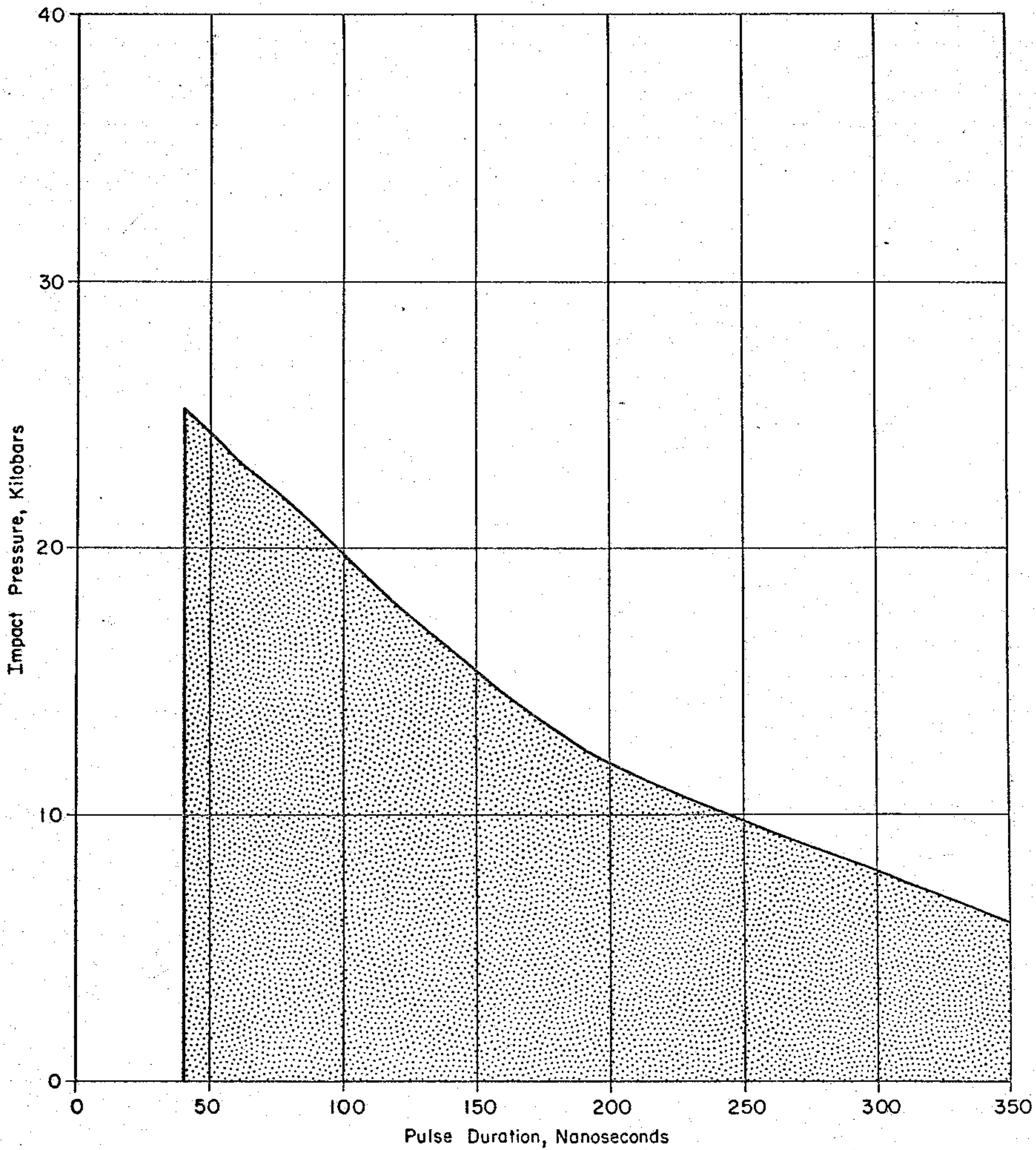

Figure 11. Operating range for 12-inch diameter, 54-inch long steel test specimens.

The 100-kilojoule capacitor bank can also be employed to initiate secondary sheet explosive such as PETN. In this application, the bank supplies the input energy necessary to vaporize a fine-wire metallic conducting mesh placed in contact with the explosive. The vaporization processes produces a pressure-temperature environment conducive to initiation of the high explosive. Ionization of the surrounding air often produces an alternate low-impedance shunt path which allows the conducting mesh to reignite shortly after vaporization has occurred. This reignition process also aids in the initiation process.

The conducting mesh is placed between two electrodes which in turn are connected to the bank output terminals. The return current path is provided by a suitable conductor, so designed as to be relatively unaffected by the Ohmic heating developed in the bank. The resultant magnetic pressure developed between the two conductors serves, when properly utilized, to more intimately couple the mesh to the explosive and more effectively transfer energy and momentum from the former to the latter.

Magnetic impulsive loading uses the energy stored in the load inductance to perform work on the flyer plate. In the case of exploding mesh initiation of HE, the energy required to vaporize the mesh is supplied by resistive heating in the load. A prime requirement is that the load resistance be greater than the resistance of the bank. For a copper mesh 18 inches long, 12 inches in diameter and 0.1-mil in thickness with the current flow directed axially, one has to good approximation a room temperature resistance of

$$R_L(o) = 3.2 \quad \text{milliohms}$$

as opposed to the internal bank resistance of 0.8 milliohm.

A 50-kilovolt system can produce voltages as large as 200 kilovolts across the mesh during vaporization. It is essential that the capacitors are not exposed to signals of that magnitude, not even momentarilly. This can be accomplished by making the load inductance large compared to the bank inductance so that the internal bank experiences only a small fraction of the vaporization voltage.

It is believed, extrapolating from studies made with a smaller 3-kilojoule of comparable ringing frequency pulsed power system, that if the load inductance is made as large as ten nanohenries, the maximum rate of change of current through the mesh, at vaporization, will be approximately 20 kiloamperes per nanosecond, thus producing an inductive voltage of 60 kilovolts across the bank and switch. It is felt that such a voltage load can be safely sustained by the bank capacitors.

More than 370 square centimeters of high explosive in contact with 400-line-per-inch electroformed copper mesh has been successfully initiated with the 3-kilojoule system to date. The electrical energy supplied to vaporize the conducting mesh was approximately one kilojoule, indicating a threshold valve of less than 3 joules per square centimeter of surface as the input energy requirement. If these figures can be linearly extrapolated to the larger pulsed-power system, the 100-kilojoule bank is capable of initiating more than 14 square feet of PETN. This valve is comparable with the surface area of the largest specimen discussed in the preceding section.

1. Brundage, R. and J. Farber; "Progress Report Impulsive Loading by Magnetic Fields Phase 2"; B-3256; EG&G, Inc., Boston, Massachusetts; 15 March 1966.

2. Jackson, J. D.; Classical Electrodynamics; John Wiley & Sons, Inc., New York, N. Y.; 1962; p. 233.

3. Farber, J. Z.; "Diffusion of Damped Sine-Wave Magnetic Fields into Metals"; B-3307; EG&G, Inc., Boston, Massachusetts; 6 May 1966.