THERMAL PARAMETERS

Heat generated by Linear Disc Resistors is dissipated mainly by radiation and convection from the exposed surface areas. Within restricted domains, mathematical models may be employed to permit heat transfer estimations.

Symbols

ΔT = Temperature Rise (°C)
W_a = Watts / Unit Exposed Surface Area ($W.cm^{-2}$)
v = Volume / Disc (cm^3)
c_m = Specific Heat Capacity of Active Material = 2J. $cm^{-3}.°C^{-1}$
Do = Disc Outside Diameter (cm)
τ = Resistor Thermal Time Constant (s)

Radiation and Convection $W_a = 0.00026(\Delta T)^{1.4}$
(ΔT = 50°C to 175°C, Do = 1.9 cm to 15.1 cm, Ambient 25°C)

Dynamic Energy
Since the active material has a negative Temperature Coefficient of Resistance, estimated energies based on Bridge Resistance will be lower than the actual. If the Temperature Coefficient is considered then a true Dynamic Energy will result.

If
E_B = Energy in Joules based on a Bridge Resistance
E_D = True Dynamic Energy
α = Temperature Coefficient of Resistance (TCR)

Then

$$E_D = \frac{2}{\alpha}(1-\sqrt{(1-\alpha E_B)}) \text{ Joules}$$

In this relationship, α is the fractional (not %) value and the negative sign has been included in the equation.

Thermal Conductivity 0.04 W / cm^2.°C / cm

Maximum Insertion Energy Ratings
Disc diameters ≤ 11.2 cm : ≤ 600 Joules / cm^3 (Infrequently)
Disc diameters > 11.2 cm : ≤ 500 Joules / cm^3 (Infrequently)

Recommended Operating Temperatures
Disc diameters ≤ 11.2 cm : ≤ 300 °C (Infrequent Operation)
Disc diameters > 11.2 cm : ≤ 250 °C (Infrequent Operation)
All Discs diameters : ≤ 150 °C (Continuous Operation)

Temperature Rise from Energy Injection ΔT (°C) = Joules (per disc) / (v x c_m) (Free Air)

Thermal Time Constant
Full Cooling τ (s) = Max Joules @ 25°C / Max Watts @ 25°C
$\geq 4\tau$

De-rating for other ambient Temperatures (Ta°C) Multiply Max Joules @ 25°C & Max Watts @ 25°C by the ratio (150 - Ta) / 125

Repetitive Thermal Impulsing:
Assuming that the Heat Transfer Coefficient α (W / cm^2.°C / cm) is constant over the operating temperature range, then the Peak Temperature Rise (ΔTp) associated with repetitive impulsing can be estimated by way of reference to a classical geometric progression ...

$$\Delta Tp\ (°C) = \Delta T \times (1 - (e^{-(t/\tau)})^n) \div (1 - e^{-(t/\tau)}) \quad \text{.....1}$$

where:
ΔT is the Temperature Rise associated with each electrical impulse (°C)
τ is the Resistor Thermal Time Constant (s)
t is the Repetition Rate (s)
n is the number of impulses

If the number of impulses (n) ➔ ∞ (ie continuous duty), then equation 1 can be simplified thus ...

$$\Delta Tp\ (°C) = \Delta T \div (1 - e^{-(t/\tau)}) \quad \text{..... 2}$$

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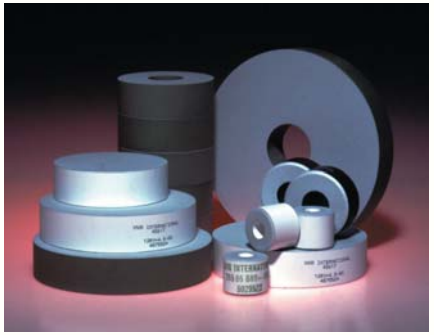
Linear Disc Resistors

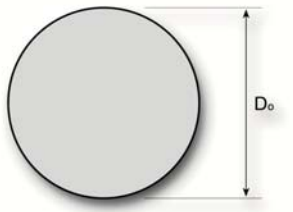
- **100% Active Material**
- **High Surge Energy Rating**
- **High Voltage Withstand**
- **Essentially Non-Inductive**
- **Wide Resistivity Range**
- **Wide Range of Geometries**
- **Air / Oil / SF6 Environments**
- **Single Disc or Modular Assemblies**
- **Custom Solutions Readily Available**
- **Free Design Service**

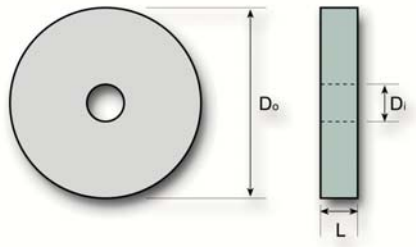


HVR Linear Disc Resistors are manufactured from a carefully blended mixture of clays, alumina and carbon. After blending, the material is pressed to the required shape, with diameters ranging from 0.3 to 15.1 cm. The Resistors are then fired at high temperature in a tunnel kiln with controlled atmosphere.

This produces a Ceramic Carbon Resistor which is 100% active material and therefore of minimum size. Aluminium is then flame-sprayed onto the flat surfaces of the resistor to provide electrical contact, and an anti-track coating is applied to the periphery to improve dielectric withstand.

With the capability of sustaining energies ranging from Joules to Mega-Joules, at frequencies up to Mega-Hz, HVR Linear Disc Resistors can be used in even the most demanding applications such as electrical transmission, traction, AC/DC drives, pulse power, dummy loads, induction heating and pulse forming networks.





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Technical Specifications

STYLE	OUTSIDE DIAMETER	RESISTOR TYPES INSIDE DIAMETER (Di)						VOLUME $v = \pi/4 \times (D_o^2 - D_i^2) \times L$				MAXIMUM JOULES				MAXIMUM WATTS	THERMAL TIME CONSTANT				WEIGHT (Volume x 2.25g / cm³)				A / L $A/L = \pi/4 \times (D_o^2 - D_i^2) \div L$				RESISTANCE RANGE	
	(Do)	SOLID	1.1	1.4	2.0	2.6	3.4	(v)				@ 25°C				@ 25°C	(τ)				(g)				(cm)				MINIMUM	MAXIMUM
Units	(cm)	(cm)						(cm³)				(J)				(W)	(Seconds)				(g)				(cm)				Ohms	
M001A	1.9	AB 378	AB 379					7.2	4.8			1800	1200			3.5	510	340			16.0	11.0			1.1	0.7			3R9	27K0
M001C	2.4	AB 704	AB 380					11.5	9.1			2875	2275			4.0	720	570			26.0	20.5			1.8	1.4			2R0	15K0
M001B	3.1	AB 419	AB 335	AB 984				19.2	16.8	15.3		4800	4200	3825		5.5	870	760	700		43.0	38.0	34.5		3.0	2.6	2.4		1R2	10K0
M002A	4.2	AB 350		AB 381	AB 045			35.2		31.3	27.2	8800		7825	6800	7.5	1170		1040	910	79.0		70.5	61.0	5.5		4.8	4.2	0R68	5K6
M002C	5.0	AB 061			AB 851			50.0	42.0			12500	10500			9.0	1390	1170			112.5	94.5			7.7	6.5			0R43	3K6
M002B	6.0	AB 389			AB 046	AB 387		72.0	64.0	58.0		18000	16000	14500		10.5	1710	1520	1380		162.0	144.0	131.0		11.1	9.9	9.0		0R33	2K4
M003C	7.4	AB 443			AB 039	AB 399	AB 409	110.0	100.0	96.0	86.0	27500	25000	24000	21500	13.0	2120	1920	1850	1650	248.0	225.0	216.0	194.0	16.9	15.7	14.8	13.4	0R22	1K0
M003B	8.2	AB 395			AB 801	AB 564	AB 886	134.0	126.0	120.0	110.0	33500	31500	30000	27500	14.0	2390	2250	2140	1960	302.0	284.0	270.0	248.0	20.8	19.6	18.7	17.2	0R18	820R0
M004A	9.4	AB 444			AB 675	AB 902	AB 565	176.0	168.0	162.0	154.0	44000	42000	40500	38500	16.5	2670	2550	2450	2330	396.0	378.0	365.0	347.0	27.3	26.1	25.2	23.7	0R12	560R0
M004C	10.2	AB 917			AB 919	AB 923	AB 926	208.0	200.0	194.0	184.0	52000	50000	48500	46000	17.5	2970	2860	2770	2630	468.0	450.0	437.0	414.0	32.2	30.9	30.1	28.6	0R10	470R0
M004B	11.2	AB 456			AB 070	AB 029	AB 403	250.0	242.0	236.0	228.0	62500	60500	59000	57000	19.5	3210	3100	3030	2920	565.0	545.0	530.0	515.0	38.8	37.6	36.7	35.2	0R082	390R0
M005C	12.7	AB 935			AB 038	AB 967	AB 460	322.0	314.0	308.0	298.0	80500	78500	77000	74500	22.0	3660	3570	3500	3390	725.0	705.0	695.0	670.0	49.9	48.6	47.8	46.3	0R068	180R0
M005B	13.7	AB 968			AB 974	AB 978	AB 946	374.0	366.0	360.0	352.0	93500	91500	90000	88000	23.5	3980	3890	3830	3740	840.0	825.0	810.0	790.0	58.0	56.8	55.9	54.5	0R056	150R0
M006C	15.1	AB 449			AB 622	AB 808	AB 410	454.0	446.0	442.0	432.0	113500	111500	110500	108000	26.0	4370	4290	4250	4150	1020.0	1005.0	995.0	970.0	70.5	69.3	68.4	66.9	0R047	120R0
		<-------- DISC LENGTHS (L) 2.54 cm -------->																											

PHYSICAL / MECHANICAL PARAMETERS

Dimension Range Outside Diameter (Do) 0.3 to 15.1 cm Standard Length (L) 2.54 cm Length (L) 1 to 5 cm

Density Nominally 2.25 g / cm^3

Shock and Vibration Linear Disc Resistors are robust and capable of absorbing transmitted mechanical shock provided direct impact is avoided.

Coefficient of Linear Expansion + 4 x 10^{-6} to + 10 x 10^{-6} per °C **Bending Strength** 30 to 60 kg.m for a 15.1 cm dia disc

Youngs Modulus 3 x 10^6 N cm^{-2} **Crushing Strength** Average value 12000 N cm^{-2}

Assembly Mounting Force Linear Disc Resistors may be assembled directly to the busbar or assembled into stacks by mounting on an appropriate tie rod. Sufficient assembly force must be maintained to provide good electrical interdisc contact over long periods of time. HVR recommend the use of several disc spring washers in series (reduces stiffness ratio) to provide the reliable mounting force described below :

Force (kg) = 120 x $(D_o - D_i)^{0.7}$ (±50%)

As a guide the total compression (deflection), from 'just nip' condition should be :

Total compression = 2 + (Number of Discs x 0.1) mm

Greater compressive forces are permissible provided the disc contact surfaces are ground flat and are free from foreign bodies, thereby minimising the risk of destructive induced bending moments.

Disc Terminations Metallised contacts are flame sprayed onto the opposing flat surfaces of the Resistor Discs. Standard metallised contacts include Aluminium, Copper, Brass, Nickel and Silver.

Anti-Track Coating Epoxy or Silicone based anti-track coatings are utilised for improvement of dielectric withstand in Air and SF6 gas.

Environmental Protection Resistor Discs can be impregnated with Silicone Varnish to reduce moisture ingress and terminals Electroless Nickel Plated to minimise corrosion.

Resistor Drying Ceramic Resistors are porous and absorb moisture, this should be removed from the discs prior to use. Dry the discs in an oven at 110 - 120°C for 24 hours. Place discs in a sealed container with silica gel.

ELECTRICAL PARAMETERS

Resistance Values Whilst E24 values are preferred, other values are readily available at no additional cost.

Resistance Tolerance +/- 20%, +/- 10% and +/- 5% available as standard.

Resistivity Range - ρ 3 Ohm cm to 30000 Ohm cm ρ = R x A/L where R = Resistance Value

Temperature Coefficient - TCR -0.05% to -0.15% per °C Temperature Rise depending on Resistivity Value.

TCR = 0.16 x $e^{-(\log\rho/1.4)}$ - 0.135 (%/°C Temperature Rise)

Voltage Coefficient - VCR -0.5% to -7.5% / kV / cm

VCR = -0.62 x $\rho^{0.22}$ (%/kV/cm) For ρ domain 10 to 7500 Ohm cm

Inductance This is negligible (nH) and the resistors may be described as non-inductive. In practice the inductance of connecting leads will be greater than that of the resistors.

Dielectric Constant (Permittivity) ε_r This is very difficult to measure and will vary according to material resistivity. As an order of merit : $\varepsilon_r \simeq 5$

Maximum Working Voltage Withstand per cm of Disc Length ($V_{working}$)

Volts (rms)	SF6	$V_{working} = 1.00 \times (R/t \times A/L)^{0.335}$	kV / cm	t Domain 10 to 50 ms	ρ Domain 10 to 7500 Ohm cm
	AIR	$V_{working} = 0.87 \times (R/t \times A/L)^{0.3}$	kV / cm	t = Insertion time in ms	
Volts (Impulse)	SF6	$V_{working} = 8.0 \times {}^{1.2}\sqrt{\text{Log}(R/2.54 \times A/L)}$	kV / cm	1.2 / 50 µs Waveform	
	AIR	$V_{working} = 4.3 \times {}^{1.2}\sqrt{\text{Log}(R/2.54 \times A/L)}$	kV / cm	1.2 / 50 µs Waveform	
	AIR	$V_{working} = 3.0 \times \text{Log}(R/2.54 \times A/L)$	kV / cm	50 / 1000 µs Waveform	
	AIR	$V_{working} = 1.5 \times (\text{Log}(R/2.54 \times A/L))^{1.25}$	kV / cm	100 / 10000 µs Waveform	

SOLID	1.1	1.4	2.0	2.6	3.4

Colour code shows different inside diameters (cm).

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