6

Magnet Wire & Lead Wire

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6.1 MAGNET WIRE

SOLID ROUND MAGNET WIRE DATA

NOMINAL DIAMETERS AND CROSS-SECTIONAL AREAS

BARE WIRE DIAMETER		WIRE GAUGE*		CROSS-SECTIONAL AREA	
Inches	mm	AWG	Metric	Cir Mils	Square mm
0.3066	7.788	0.5		94000	47.632
0.3000	7.620			90000	45.604
0.2953	7.500		7.5	87190	44.179
0.2893	7.348	1		83690	42.409
0.2795	7.100		7.1	78140	39.592
0.2760	7.010			76180	38.599
0.2730	6.934	1.5		74530	37.764
0.2638	6.700		6.7	69580	35.257
0.2576	6.543	2		66360	33.624
0.2520	6.401			63500	32.178
0.2480	6.300		6.3	61520	31.173
0.2431	6.175	2.5		59100	29.945
0.2362	6.000		6.0	55800	28.274
0.2320	5.893			53820	27.273
0.2294	5.827	3		52620	26.665
0.2205	5.600		5.6	48610	24.630
0.2165	5.499	3.5		46870	23.751
0.2120	5.385			44940	22.774
0.2087	5.300		5.3	43540	22.062
0.2043	5.189	4		41740	21.149
0.1969	5.000		5.0	38750	19.635
0.1928	4.897	4.5		37170	18.835
0.1920	4.877			36860	18.679
0.1870	4.750		4.75	34970	17.721
0.1819	4.620	5		33090	16.766
0.1772	4.500		4.5	31390	15.904
0.1760	4.470			30980	15.696
0.1717	4.361	5.5		29480	14.938
0.1673	4.250		4.25	28000	14.186
0.1620	4.115	6		26240	13.298
0.1600	4.064			25600	12.972
0.1575	4.000		4.0	24800	12.566
0.1529	3.884	6.5		23380	11.846
0.1476	3.750		3.75	21800	11.045
0.1443	3.665	7		20820	10.551
0.1440	3.658			20740	10.507
0.1398	3.550		3.55	19530	9.898
0.1362	3.459	7.5		18550	9.400
0.1319	3.350		3.35	17390	8.814
0.1285	3.264	8		16510	8.367
0.1280	3.251			16380	8.302
0.1240	3.150		3.15	15380	7.793

BARE WIRE DIAMETER		WIRE GAUGE*		CROSS-SECTIONAL AREA	
Inches	mm	AWG	Metric	Cir Mils	Square mm
0.1213	3.081	8.5		14710	7.456
0.1181	3.000		3.0	13950	7.069
0.1160	2.946			13460	6.818
0.1144	2.906	9		13090	6.631
0.1102	2.800		2.8	12150	6.158
0.1080	2.743	9.5		11660	5.910
0.1043	2.650		2.65	10880	5.515
0.1040	2.642			10820	5.481
0.1019	2.588	10		10380	5.261
0.0984	2.500		2.5	9690	4.909
0.0962	2.443	10.5		9250	4.689
0.0929	2.360		2.36	8630	4.374
0.0920	2.337			8460	4.289
0.0907	2.304	11		8230	4.168
0.0882	2.240		2.24	7780	3.941
0.0856	2.174	11.5		7330	3.713
0.0835	2.120		2.12	6970	3.536
0.0808	2.052	12		6530	3.308
0.0800	2.032			6400	3.243
0.0787	2.000		2.0	6200	3.142
0.0763	1.938	12.5		5820	2.950
0.0748	1.900		1.9	5600	2.835
0.0720	1.829	13		5180	2.627
0.0709	1.800		1.8	5020	2.545
0.0679	1.725	13.5		4610	2.336
0.0669	1.700		1.7	4480	2.270
0.0641	1.628	14		4110	2.082
0.0640	1.626			4100	2.075
0.0630	1.600		1.6	3970	2.011
0.0605	1.537	14.5		3660	1.855
0.0591	1.500		1.5	3490	1.767
0.0571	1.450	15		3260	1.652
0.0560	1.422			3140	1.589
0.0551	1.400		1.4	3040	1.539
0.0539	1.369	15.5		2910	1.472
0.0520	1.320		1.32	2700	1.368
0.0508	1.290	16		2580	1.308
0.0492	1.250		1.25	2420	1.227
0.0480	1.219	16.5		2300	1.167
0.0465	1.180		1.18	2160	1.094
0.0453	1.151	17		2050	1.040
0.0441	1.120		1.12	1940	0.985

* Wire Gage Abbreviations: AWG is an abbreviation for American Wire Gage. Square inches x 1.273×10^6 = circular mils. Square millimeters equals the actual area of the wire.

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SOLID ROUND MAGNET WIRE DATA (Continued)

NOMINAL DIAMETERS AND CROSS-SECTIONAL AREAS

BARE WIRE DIAMETER		WIRE GAUGE*		CROSS-SECTIONAL AREA	
Inches	mm	AWG	Metric	Cir Mils	Square mm
0.0427	1.085	17.5		1820	0.924
0.0417	1.060		1.06	1740	0.882
0.0403	1.024	18		1620	0.823
0.0400	1.016			1600	0.811
0.0394	1.000		1.0	1550	0.785
0.0380	0.965	18.5		1440	0.732
0.0374	0.950		0.95	1400	0.709
0.0360	0.914			1300	0.657
0.0359	0.912	19		1290	0.653
0.0354	0.900		0.9	1260	0.636
0.0339	0.861	19.5		1150	0.582
0.0335	0.850		0.85	1120	0.567
0.0320	0.813	20		1020	0.519
0.0315	0.800		0.8	992	0.503
0.0302	0.767	20.5		912	0.462
0.0295	0.750		0.75	872	0.442
0.0285	0.724	21		812	0.412
0.0280	0.711			784	0.397
0.0280	0.710		0.71	781	0.396
0.0269	0.683	21.5		724	0.367
0.0264	0.670		0.67	696	0.353
0.0253	0.643	22		640	0.324
0.0248	0.630		0.63	615	0.312
0.0240	0.610			576	0.292
0.0239	0.607	22.5		571	0.289
0.0236	0.600		0.6	558	0.283
0.0226	0.574	23		511	0.259
0.0220	0.560		0.56	486	0.246
0.0220	0.559			484	0.245
0.0213	0.541	23.5		454	0.230
0.0209	0.530		0.53	435	0.221
0.0201	0.511	24		404	0.205
0.0200	0.508			400	0.203
0.0197	0.500		0.5	388	0.196
0.0190	0.483	24.5		361	0.183
0.0187	0.475		0.475	350	0.177
0.0180	0.457			324	0.164
0.0179	0.455	25		320	0.162
0.0177	0.450		0.45	314	0.159
0.0169	0.429	25.5		286	0.145
0.0167	0.425		0.425	280	0.142
0.0164	0.417			269	0.136
0.0159	0.404	26		253	0.128
0.0157	0.400		0.4	248	0.126
0.0150	0.381	26.5		225	0.114

BARE WIRE DIAMETER		WIRE GAUGE*		CROSS-SECTIONAL AREA	
Inches	mm	AWG	Metric	Cir Mils	Square mm
0.0148	0.376			219	0.111
0.0148	0.375		0.375	218	0.110
0.0142	0.361	27		202	0.102
0.0140	0.355		0.355	195	0.0990
0.0136	0.345			185	0.0937
0.0134	0.340	27.5		180	0.0910
0.0132	0.335		0.335	174	0.0881
0.0126	0.320	28		159	0.0804
0.0124	0.315		0.315	154	0.0779
0.0119	0.302	28.5		142	0.0718
0.0118	0.300		0.3	140	0.0707
0.0116	0.295			135	0.0682
0.0113	0.287	29		128	0.0647
0.0110	0.280		0.28	122	0.0616
0.0108	0.274			117	0.0591
0.0106	0.269	29.5		112	0.0569
0.0104	0.265		0.265	109	0.0552
0.0100	0.254	30		100	0.0507
0.0098	0.250		0.25	96.9	0.0491
0.0095	0.241	30.5		90.3	0.0457
0.0093	0.236		0.236	86.3	0.0437
0.0092	0.234			84.6	0.0429
0.0089	0.226	31		79.2	0.0401
0.0088	0.224		0.224	77.8	0.0394
0.0084	0.213			70.6	0.0358
0.0083	0.212		0.212	69.7	0.0353
0.0080	0.203	32		64.0	0.0324
0.0079	0.200		0.2	62.0	0.0314
0.0076	0.193			57.8	0.0293
0.0075	0.190		0.19	56.0	0.0284
0.0071	0.180	33	0.18	50.4	0.0254
0.0068	0.173			46.2	0.0234
0.0067	0.170		0.17	44.8	0.0227
0.0063	0.160	34	0.16	39.7	0.0201
0.0060	0.152			36.0	0.0182
0.0059	0.150		0.15	34.9	0.0177
0.0056	0.142	35		31.4	0.0159
0.0055	0.140		0.14	30.4	0.0154
0.0052	0.132		0.132	27.0	0.0137
0.0050	0.127	36		25.0	0.0127
0.0049	0.125		0.125	24.2	0.0123
0.0048	0.122			23.0	0.0117

* Wire Gage Abbreviations: AWG is an abbreviation for American Wire Gage. Square inches x 1.273 x 10^6 = circular mils. Square millimeters equals the actual area of the wire.

SOLID ROUND COPPER WIRE DATA—AWG SIZES

SIZE	DIAMETER—INCHES					AREA	BARE WIRE WEIGHT			DC RESISTANCE*		
	NOMINAL	MAXIMUM OVERALL FILM COATING †				CIR.	LBS PER	KG PER	FEET	OHMS PER	OHMS	OHMS
AWG	BARE WIRE	SINGLE	HEAVY	TRIPLE	QUAD	MILS	1000 FT	KM	PER LB	1000 FT	PER KM	PER LB
0.5	0.3066					94000	284.5	423.9	3.514	0.1103	0.3619	0.0003877
1	0.2893					83690	253.3	377.4	3.947	0.1239	0.4065	0.0004891
1.5	0.2730					74530	225.6	336.1	4.433	0.1392	0.4567	0.0006168
2	0.2576					66360	200.9	299.3	4.978	0.1563	0.5128	0.0007781
2.5	0.2431					59100	178.9	266.6	5.590	0.1755	0.5758	0.0009810
3	0.2294					52620	159.3	237.4	6.278	0.1971	0.6467	0.001237
3.5	0.2165					46870	141.9	211.4	7.048	0.2213	0.7261	0.001560
4	0.2043		0.2098			41740	126.3	188.2	7.915	0.2485	0.8153	0.001967
4.5	0.1928		0.1983			37170	112.5	167.6	8.887	0.2790	0.9154	0.002480
5	0.1819		0.1872			33090	100.2	149.3	9.984	0.3135	1.029	0.003130
5.5	0.1717		0.1770			29480	89.24	133.0	11.21	0.3518	1.153	0.003942
6	0.1620		0.1671			26240	79.44	118.4	12.59	0.3952	1.297	0.004975
6.5	0.1529		0.1580			23380	70.77	105.5	14.13	0.4436	1.456	0.006269
7	0.1443		0.1491			20820	63.03	93.91	15.87	0.4981	1.634	0.007902
7.5	0.1362		0.1410			18550	56.15	83.66	17.81	0.5591	1.834	0.009957
8	0.1285		0.1332			16510	49.98	74.47	20.01	0.6281	2.061	0.01257
8.5	0.1213		0.1260			14710	44.54	66.36	22.45	0.7049	2.313	0.01583
9	0.1144		0.1190			13090	39.61	59.02	25.24	0.7925	2.600	0.02000
9.5	0.1080		0.1126			11660	35.31	52.61	28.32	0.8892	2.918	0.02518
10	0.1019		0.1064			10380	31.43	46.83	31.82	0.9988	3.277	0.03178
10.5	0.0962		0.1007			9250	28.01	41.73	35.70	1.121	3.678	0.04001
11	0.0907		0.0951			8230	24.90	37.10	40.16	1.261	4.137	0.05063
11.5	0.0856		0.0900			7330	22.18	33.05	45.09	1.415	4.643	0.06382
12	0.0808		0.0850			6530	19.76	29.44	50.60	1.589	5.214	0.08039
12.5	0.0763		0.0805			5820	17.62	26.25	56.75	1.782	5.847	0.1011
13	0.0720		0.0762			5180	15.69	23.38	63.73	2.001	6.565	0.1275
13.5	0.0679		0.0721			4610	13.96	20.80	71.66	2.250	7.382	0.1612
14	0.0641	0.0666	0.0682	0.0698	0.0714	4110	12.44	18.54	80.40	2.524	8.281	0.2030
14.5	0.0605	0.0630	0.0646	0.0666	0.0678	3660	11.08	16.51	90.26	2.834	9.298	0.2557
15	0.0571	0.0594	0.0610	0.0625	0.0640	3260	9.869	14.70	101.3	3.181	10.44	0.3223
15.5	0.0539	0.0562	0.0578	0.0597	0.0608	2910	8.794	13.10	113.7	3.570	11.71	0.4059
16	0.0508	0.0531	0.0545	0.0560	0.0574	2580	7.811	11.64	128.0	4.019	13.19	0.5145
16.5	0.0480	0.0503	0.0517	0.0532	0.0546	2300	6.974	10.39	143.4	4.502	14.77	0.6454
17	0.0453	0.0475	0.0488	0.0502	0.0516	2050	6.212	9.256	161.0	5.054	16.58	0.8136
17.5	0.0427	0.0449	0.0462	0.0476	0.0490	1820	5.519	8.223	181.2	5.688	18.66	1.031
18	0.0403	0.0424	0.0437	0.0450	0.0464	1620	4.916	7.325	203.4	6.386	20.95	1.299
18.5	0.0380	0.0401	0.0414	0.0427	0.0441	1440	4.371	6.513	228.8	7.182	23.56	1.643
19	0.0359	0.0379	0.0391	0.0404	0.0418	1290	3.901	5.812	256.3	8.047	26.40	2.063
19.5	0.0339	0.0359	0.0371	0.0384	0.0398	1150	3.479	5.184	287.5	9.025	29.61	2.594
20	0.0320	0.0340	0.0351	0.0363	0.0376	1020	3.100	4.619	322.6	10.13	33.24	3.268
20.5	0.0302	0.0322	0.0333	0.0345	0.0358	912	2.761	4.114	362.2	11.37	37.31	4.119
21	0.0285	0.0303	0.0315	0.0326	0.0339	812	2.459	3.664	406.7	12.77	41.90	5.193
21.5	0.0269	0.0287	0.0299	0.0310	0.0323	724	2.190	3.263	456.5	14.33	47.02	6.544
22	0.0253	0.0270	0.0281	0.0292	0.0305	640	1.938	2.888	516.1	16.20	53.15	8.363
22.5	0.0239	0.0256	0.0267	0.0278	0.0291	571	1.729	2.576	578.4	18.16	59.58	10.50
23	0.0226	0.0243	0.0253	0.0263	0.0277	511	1.546	2.304	646.8	20.31	66.64	13.13
23.5	0.0213	0.0230	0.0240	0.0250	0.0264	454	1.373	2.046	728.2	22.86	75.00	16.65
24	0.0201	0.0217	0.0227	0.0236	0.0250	404	1.223	1.822	817.7	25.67	84.22	20.99
24.5	0.0190	0.0206	0.0216	0.0225	0.0239	361	1.093	1.629	915.1	28.73	94.26	26.29
25	0.0179	0.0194	0.0203	0.0212	0.0226	320	0.9699	1.445	1031	32.37	106.2	33.37
25.5	0.0169	0.0184	0.0193	0.0202	0.0216	286	0.8645	1.288	1157	36.31	119.1	42.00

* Resistance values based on copper of 100% conductivity at 20°C (68°F).

† Reference: NEMA Std. MW 1000, Tables 1-1, 1-2 and 1-3.

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SOLID ROUND COPPER WIRE DATA—AWG SIZES (Continued)

SIZE	DIAMETER—INCHES					AREA	BARE WIRE WEIGHT			DC RESISTANCE*		
	NOMINAL	MAXIMUM OVERALL FILM COATING †				CIR.	LBS PER	KG PER	FEET	OHMS PER	OHMS	OHMS
AWG	BARE WIRE	SINGLE	HEAVY	TRIPLE	QUAD	MILS	1000 FT	KM	PER LB	1000 FT	PER KM	PER LB
26	0.0159	0.0173	0.0182	0.0191	0.0204	253	0.7652	1.140	1307	41.02	134.6	53.61
26.5	0.0150	0.0164	0.0173	0.0182	0.0195	225	0.6811	1.015	1468	46.10	151.3	67.68
27	0.0142	0.0156	0.0164	0.0173	0.0184	202	0.6104	0.909	1638	51.44	168.8	84.27
27.5	0.0134	0.0148	0.0156	0.0165	0.0176	180	0.5435	0.810	1840	57.76	189.5	106.3
28	0.0126	0.0140	0.0147	0.0155	0.0165	159	0.4806	0.716	2081	65.33	214.3	135.9
28.5	0.0119	0.0133	0.0140	0.0148	0.0158	142	0.4286	0.639	2333	73.24	240.3	170.9
29	0.0113	0.0126	0.0133	0.0141	0.0151	128	0.3865	0.576	2587	81.22	266.5	210.1
29.5	0.0106	0.0119	0.0126	0.0134	0.0144	112	0.3401	0.510	2940	92.31	302.9	271.4
30	0.0100	0.0112	0.0119	0.0128	0.0136	100	0.3027	0.451	3304	103.7	340.2	342.6
30.5	0.0095	0.0107	0.0114	0.0123	0.0131	90.3	0.2732	0.407	3660	114.9	377.0	420.7
31	0.0089	0.0100	0.0108	0.0114	0.0124	79.2	0.2398	0.357	4171	130.9	429.5	546.1
32	0.0080	0.0091	0.0098	0.0103	0.0113	64.0	0.1937	0.289	5162	162.1	531.9	836.5
33	0.0071	0.0081	0.0088	0.0092	0.0102	50.4	0.1526	0.227	6553	205.7	674.9	1348
34	0.0063	0.0072	0.0078	0.0082	0.0091	39.7	0.1201	0.179	8324	261.3	857.3	2175
35	0.0056	0.0064	0.0070	0.0074	0.0082	31.4	0.09493	0.141	10530	330.7	1085	3484
36	0.0050	0.0058	0.0063	0.0067	0.0074	25.0	0.07567	0.113	13210	414.9	1361	5482
37	0.0045	0.0053	0.0057	0.0060	0.0067	20.2	0.0613	0.091	16310	512.2	1681	8356
38	0.0040	0.0047	0.0051	0.0054	0.0060	16.0	0.04843	0.072	20640	648.2	2127	13380
39	0.0035	0.0041	0.0045	0.0048	0.0053	12.2	0.03708	0.055	26960	846.7	2778	22830
40	0.0031	0.0037	0.0040	0.0043	0.0047	9.61	0.02909	0.043	34370	1079	3540	37100
41	0.0028	0.0034	0.0036	0.0040	0.0043	7.84	0.02373	0.035	42130	1323	4341	55740
42	0.0025	0.0030	0.0033	0.0035	0.0039	6.25	0.01892	0.028	52850	1659	5443	87710
43	0.0022	0.0026	0.0029	0.0032	0.0035	4.84	0.01465	0.022	68250	2143	7031	146200
44	0.0020	0.0024	0.0027	0.0030	0.0033	4.00	0.01211	0.020	82580	2593	8508	214100
45	0.00176	0.00220	0.0024	0.0027	0.0029	3.10	0.00938	0.01398	106600	3348	1098	357000
46	0.00157	0.00200	0.0021	0.0024	0.0026	2.46	0.00746	0.01112	134000	4208	1381	563900
47	0.00140	0.00170	0.0019			1.96	0.00593	0.00884	168500	5292	1736	891800
48	0.00124	0.00150	0.0017			1.54	0.00465	0.00693	214800	6745	2213	1449000
49	0.00111	0.00130	0.0015			1.23	0.00373	0.00556	268100	8418	2762	2257000
50	0.00099	0.00120	0.0014			0.980	0.00297	0.00443	337000	10580	3471	3566000
51	0.00088	0.00110				0.774	0.00234	0.00349	426600	13390	4393	5713000
52	0.00078	0.00100				0.608	0.00184	0.00274	543000	17040	5591	9256000
53	0.00070	0.00085				0.490	0.00148	0.00221	674200	21160	6943	14270000
54	0.00062	0.00075				0.384	0.00116	0.00173	859400	26980	8851	23180000
55	0.00055	0.00070				0.302	0.00092	0.00137	1092000	34280	112500	37440000
56	0.00049	0.00065				0.240	0.00073	0.00109	1376000	43190	141700	59430000

* Resistance values based on copper of 100% conductivity at 20°C (68°F).

† Reference: NEMA Std. MW 1000, Tables 1-1, 1-2 and 1-3.

SOLID ROUND COPPER WIRE DATA—METRIC SIZES

NOMINAL BARE WIRE DATA

DIAMETER		AREA		WEIGHT		DC RESISTANCE*		
MM	INCHES	SQUARE MM	CIRCULAR MILS	KG PER KM	LBS PER 1000 FT	OHMS PER KM	OHMS PER 1000 FT	OHMS PER KG
7.500	0.2953	44.179	87180	392.7	263.9	0.3902	0.1189	0.0009938
7.100	0.2795	39.592	78130	352.0	236.6	0.4354	0.1327	0.001238
6.700	0.2638	35.257	69570	313.4	210.6	0.4890	0.1490	0.001561
6.300	0.2480	31.173	61510	277.1	186.2	0.5530	0.1686	0.001996
6.000	0.2362	28.274	55800	251.4	167.0	0.6097	0.1858	0.002426
5.600	0.2205	24.630	48600	219.0	147.2	0.6999	0.2133	0.003198
5.300	0.2087	22.062	43530	196.1	131.8	0.7814	0.2382	0.003985
5.000	0.1969	19.635	38750	174.6	117.3	0.8780	0.2676	0.005031
4.750	0.1870	17.721	34970	157.5	105.9	0.9729	0.2965	0.006177
4.500	0.1772	15.904	31380	141.4	95.03	1.084	0.3304	0.007669
4.250	0.1673	14.186	27990	126.1	84.75	1.215	0.3703	0.009639
4.000	0.1575	12.566	24800	111.7	75.07	1.372	0.4182	0.01228
3.750	0.1476	11.045	21790	98.19	65.99	1.561	0.4758	0.01590
3.550	0.1398	9.898	19530	87.99	59.14	1.742	0.5310	0.01980
3.350	0.1319	8.814	17390	78.36	52.67	1.956	0.5962	0.02497
3.150	0.1240	7.793	15370	69.28	46.56	2.212	0.6742	0.03194
3.000	0.1181	7.069	13950	62.84	42.23	2.439	0.7434	0.03882
2.800	0.1102	6.158	12150	54.74	36.79	2.800	0.8534	0.05115
2.650	0.1043	5.515	10880	49.03	32.95	3.126	0.9528	0.06378
2.500	0.0984	4.909	9690	43.64	29.33	3.512	1.070	0.08049
2.360	0.0929	4.374	8630	38.89	26.14	3.941	1.201	0.1014
2.240	0.0882	3.941	7780	35.03	23.54	4.375	1.334	0.1249
2.120	0.0835	3.530	6970	31.38	21.09	4.884	1.489	0.1557
2.000	0.0787	3.142	6200	27.93	18.77	5.488	1.673	0.1965
1.900	0.0748	2.835	5600	25.21	16.94	6.080	1.853	0.2413
1.800	0.0709	2.545	5020	22.62	15.20	6.775	2.065	0.2995
1.700	0.0669	2.270	4480	20.18	13.56	7.595	2.315	0.3764
1.600	0.0630	2.011	3970	17.87	12.01	8.574	2.613	0.4796
1.500	0.0591	1.767	3490	15.71	10.56	9.756	2.974	0.6213
1.400	0.0551	1.539	3040	13.69	9.201	11.20	3.414	0.8190
1.320	0.0520	1.368	2700	12.17	8.179	12.60	3.840	1.037
1.250	0.0492	1.227	2420	10.91	7.333	14.05	4.282	1.288
1.180	0.0465	1.094	2160	9.722	6.534	15.76	4.804	1.621
1.120	0.0441	0.985	1940	8.758	5.886	17.50	5.334	1.999
1.060	0.0417	0.882	1740	7.845	5.273	19.54	5.956	2.493
1.000	0.0394	0.785	1550	6.982	4.693	21.95	6.690	3.148
0.950	0.0374	0.709	1400	6.301	4.235	24.32	7.413	3.859
0.900	0.0354	0.636	1260	5.656	3.801	27.10	8.260	4.795
0.850	0.0335	0.567	1120	5.045	3.391	30.38	9.260	6.034
0.800	0.0315	0.503	992	4.469	3.004	34.30	10.45	7.667
0.750	0.0295	0.442	872	3.927	2.639	39.02	11.89	9.929
0.710	0.0280	0.396	781	3.52	2.366	43.54	13.27	12.37
0.670	0.0264	0.353	696	3.134	2.106	48.90	14.90	15.57
0.630	0.0248	0.312	615	2.771	1.862	55.30	16.86	19.93
0.600	0.0236	0.283	558	2.514	1.690	60.97	18.58	24.22
0.560	0.0220	0.246	486	2.190	1.472	69.99	21.33	32.05
0.530	0.0209	0.221	435	1.961	1.318	78.14	23.82	39.72
0.500	0.0197	0.196	388	1.746	1.173	87.80	26.76	50.49

* Resistance values based on copper of 100% conductivity at 20°C (68°F).

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SOLID ROUND COPPER WIRE DATA—METRIC SIZES (Continued)

NOMINAL BARE WIRE DATA

DIAMETER		AREA		WEIGHT		DC RESISTANCE*		
MM	INCHES	SQUARE MM	CIRCULAR MILS	KG PER KM	LBS PER 1000 FT	OHMS PER KM	OHMS PER 1000 FT	OHMS PER KG
0.475	0.0187	0.177	350	1.575	1.059	97.29	29.65	61.92
0.450	0.0177	0.159	314	1.414	0.9503	108.4	33.04	76.73
0.425	0.0167	0.142	280	1.261	0.8475	121.5	37.03	96.20
0.400	0.0157	0.126	248	1.117	0.7507	137.2	41.82	122.2
0.375	0.0148	0.110	218	0.9819	0.6599	156.1	47.58	160.3
0.355	0.0140	0.0990	195	0.8799	0.5914	174.2	53.10	197.9
0.335	0.0132	0.0881	174	0.7836	0.5267	195.6	59.62	249.9
0.315	0.0124	0.0779	154	0.6928	0.4656	221.2	67.42	319.6
0.300	0.0118	0.0707	140	0.6284	0.4223	243.9	74.34	388.1
0.280	0.0110	0.0616	122	0.5474	0.3679	280.0	85.34	511.2
0.265	0.0104	0.0552	109	0.4903	0.3295	312.6	95.28	636.6
0.250	0.0098	0.0491	96.9	0.4364	0.2933	351.2	107.1	804.6
0.236	0.0093	0.0437	86.3	0.3889	0.2614	394.1	120.1	1016
0.224	0.0088	0.0394	77.8	0.3503	0.2354	437.5	133.4	1250
0.212	0.0083	0.0353	69.7	0.3138	0.2109	488.4	148.9	1557
0.200	0.0079	0.0314	62.0	0.2793	0.1877	548.8	167.3	1967
0.190	0.0075	0.0284	56.0	0.2521	0.1694	608.0	185.3	2405
0.180	0.0071	0.0254	50.2	0.2262	0.1520	677.5	206.5	3007
0.170	0.0067	0.0227	44.8	0.2018	0.1356	759.5	231.5	3764
0.160	0.0063	0.0201	39.7	0.1787	0.1201	857.4	261.3	4801
0.150	0.0059	0.0177	34.9	0.1571	0.1056	975.6	297.4	6192
0.140	0.0055	0.0154	30.4	0.1369	0.0920	1120	341.4	8179
0.132	0.0052	0.0137	27.0	0.1217	0.0818	1260	384.0	10330
0.125	0.0049	0.0123	24.2	0.1091	0.0733	1405	428.2	12820
0.118	0.0046	0.0109	21.6	0.0972	0.0653	1576	480.4	16330
0.112	0.0044	0.00985	19.4	0.0876	0.0589	1750	533.4	19990
0.106	0.0042	0.00882	17.4	0.0785	0.0527	1954	595.6	24930
0.100	0.0039	0.00785	15.5	0.0698	0.0463	2195	669.0	31480
0.095	0.0037	0.00709	14.0	0.0630	0.0424	2432	741.3	38590
0.090	0.0035	0.00636	12.6	0.0566	0.0380	2710	826.0	47950
0.085	0.0033	0.00567	11.2	0.0505	0.0339	3038	926.0	60340
0.080	0.0031	0.00503	9.92	0.0447	0.0300	3430	1045	76670
0.075	0.0030	0.00442	8.72	0.0393	0.0264	3902	1189	99290
0.071	0.0028	0.00396	7.81	0.0352	0.0237	4354	1327	123700
0.067	0.0026	0.00353	6.96	0.0313	0.0211	4890	1490	155700
0.063	0.0025	0.00312	6.15	0.0277	0.0186	5530	1686	199300
0.060	0.0024	0.00283	5.58	0.0251	0.0169	6097	1858	242200
0.056	0.0022	0.00246	4.86	0.0219	0.0147	6999	2133	320500
0.053	0.0021	0.00221	4.35	0.0196	0.0132	7814	2382	397200
0.050	0.0020	0.00196	3.88	0.0175	0.0117	8780	2676	504900

* Resistance values based on copper of 100% conductivity at 20°C (68°F).

SOLID ROUND BARE ALUMINUM WIRE DATA—AWG SIZES

NOMINAL DATA

SIZE	DIAMETER	AREA	WEIGHT		DC RESISTANCE*	
AWG	INCHES	CIRCULAR MILS	LBS PER 1000 FT	FEET PER LB	OHMS PER 1000 FT	OHMS PER LB
0.5	0.3066	94000	86.58	11.55	0.1785	0.002062
1	0.2893	83690	77.08	12.97	0.2005	0.002601
1.5	0.2730	74530	68.64	14.57	0.2252	0.003280
2	0.2576	66360	61.12	16.36	0.2529	0.004138
2.5	0.2431	59100	54.43	18.37	0.2840	0.005217
3	0.2294	52620	48.47	20.63	0.3189	0.006580
3.5	0.2165	46870	43.17	23.16	0.3580	0.008294
4	0.2043	41740	38.44	26.01	0.4021	0.01046
4.5	0.1928	37170	34.24	29.21	0.4515	0.01319
5	0.1819	33090	30.47	32.81	0.5072	0.01664
5.5	0.1717	29480	27.15	36.83	0.5693	0.02096
6	0.1620	26240	24.17	41.37	0.6395	0.02646
6.5	0.1529	23380	21.53	46.44	0.7179	0.03334
7	0.1443	20820	19.18	52.14	0.8060	0.04202
7.5	0.1362	18550	17.09	58.53	0.9047	0.05295
8	0.1285	16510	15.21	65.75	1.016	0.06683
8.5	0.1213	14710	13.55	73.79	1.141	0.08416
9	0.1144	13090	12.05	82.96	1.282	0.1064
9.5	0.1080	11660	10.74	93.08	1.439	0.1339
10	0.1019	10380	9.564	104.6	1.616	0.1690
10.5	0.0962	9250	8.524	117.3	1.813	0.2128
11	0.0907	8230	7.577	132.0	2.040	0.2692
11.5	0.0856	7330	6.749	148.2	2.290	0.3394
12	0.0808	6530	6.013	166.3	2.571	0.4275
12.5	0.0763	5820	5.362	186.5	2.883	0.5376
13	0.0720	5180	4.775	209.4	3.237	0.6780
13.5	0.0679	4610	4.246	235.5	3.640	0.8572
14	0.0641	4110	3.784	264.2	4.084	1.079
14.5	0.0605	3660	3.371	296.6	4.585	1.360
15	0.0571	3260	3.003	333.0	5.147	1.714
15.5	0.0539	2910	2.676	373.7	5.777	2.159
16	0.0508	2580	2.377	420.7	6.503	2.736
16.5	0.0480	2300	2.122	471.2	7.284	3.432
17	0.0453	2050	1.890	529.1	8.178	4.327
17.5	0.0427	1820	1.679	595.5	9.204	5.481
18	0.0403	1620	1.496	668.5	10.33	6.908
18.5	0.0380	1440	1.330	751.9	11.62	8.739
19	0.0359	1290	1.187	842.4	13.02	10.97
19.5	0.0339	1150	1.058	944.8	14.60	13.80
20	0.0320	1020	0.9431	1060	16.39	17.38
20.5	0.0302	912	0.8400	1190	18.40	21.91
21	0.0285	812	0.7481	1337	20.66	27.62
21.5	0.0269	724	0.6665	1500	23.19	34.80
22	0.0253	640	0.5895	1696	26.22	44.47
22.5	0.0239	571	0.5261	1901	29.38	55.84
23	0.0226	511	0.4704	2126	32.86	69.85
23.5	0.0213	454	0.4179	2393	36.99	88.52
24	0.0201	404	0.3721	2687	41.54	111.6
24.5	0.0190	361	0.3325	3008	46.49	139.8
25	0.0179	320	0.2951	3389	52.38	177.5
25.5	0.0169	286	0.2631	3801	58.76	223.4
26	0.0159	253	0.2328	4295	66.38	285.1
26.5	0.0150	225	0.2072	4825	74.59	359.9
27	0.0142	202	0.1857	5384	83.23	448.1
27.5	0.0134	180	0.1654	6047	93.46	565.1
28	0.0126	159	0.1462	6839	105.7	722.9
29	0.0113	128	0.1176	8503	131.4	1118
30	0.0100	100	0.0921	10860	167.8	1822

* Resistance values based on aluminum of 61.8% conductivity at 20°C (68°F).

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Combination tables for round magnet wire changes

By Mike Howell, EASA Technical Support Specialist

Verification of as-found winding data is best practice for all stator rewinds, and required for rewinds covered by the EASA Accreditation Program. With tools like EASA's *AC Motor Verification & Redesign* software, this can be done quickly and easily. EASA's technical support staff will even verify member's data free of charge, so there's no reason to skip this important step. Besides, failure to identify and correct issues with the original data often results in wasted time and materials and may even cost the service center an additional rewind.

WIRE SIZE CHANGES

Once the data has been verified, it's often necessary to change the wire size. This is inherent with most redesigns where the number of turns per slot is changed. It's also routinely done to accommodate the service center's wire inventory.

While changing wire size is easy with EASA's verification and redesign software, various situations restrict winders to pen-and-paper methods that typically have a higher risk for error. Minimizing the manual calculations associated with such methods can increase process efficiency while reducing errors.

Assume from this point forward that the as-found winding data has been deemed acceptable and that all calculations will be performed manually.

Determine original conductor area

The first step is to determine the original conductor area per turn. Using a calibrated micrometer, measure the diameter of each strand with the insulation removed, look up its cross-sectional area in a published reference table, and then sum the areas for all of the conductors. Pages 6-2 and 6-3 provide a large selection of solid round magnet wire data across several standards (see for an example of the format).

Determine target conductor area

The formula for calculating the target conductor area per turn for the new winding is:

$A_2 = A_1 \cdot T_1 / T_2$

Where:

A_2 is the new conductor area

A_1 is the original conductor area

T_1 is the original turn count per slot

T_2 is the new turn count per slot.

Ideally, if the number of turns per slot does not change, the new conductor area should be equal to the original conductor area. EASA recommends that service centers not decrease the calculated new conductor area by more than 2%.

Increases in total conductor area are beneficial, providing there is adequate slot space. Before choosing a larger diameter conductor, however, the winder should make sure the slot opening is wide enough to insert at least two strands of the larger wire simultaneously.

FIGURE 6-1

BARE WIRE DIAMETER		WIRE GAUGE*		CROSS-SECTIONAL AREA	
Inches	mm	AWG	Metric	Cir Mils	Square mm
0.0427	1.085	17.5		1820	0.924
0.0417	1.060		1.06	1740	0.882
0.0403	1.024	18		1620	0.823
0.0400	1.016			1600	0.811
0.0394	1.000		1.0	1550	0.785
0.0380	0.965	18.5		1440	0.732
0.0374	0.950		0.95	1400	0.709
0.0360	0.914			1300	0.657
0.0359	0.912	19		1290	0.653

* AWG is an abbreviation for American Wire Gage. Square inches x 1.273×10^6 = circular mils. Square millimeters equals the actual area of the wire.

Solid round magnet wire data from Pages 6-2 and 6-3.

Units

Note that the unit chosen for the conductor area does not matter, so long as it is consistent with the materials available and familiar to the technician performing the calculations. The circular mil (CM) is used in this article and accompanying tables, but it would be equally correct to use the square inch (in^2) or square millimeter (mm^2), providing units are used consistently (1 mm^2 → 1974 CM → 0.00155 in^2).

Combination tables

Wire size changes are fairly straightforward, but finding acceptable equivalent size combinations manually can be tedious when working with several wires in hand, especially if completely different sizes are used. Before the era of computer-aided design, motor manufacturers often developed internal tools like wire combination tables to make this process easier.

Similarly, Tables 1, 2 and 3 (below) provide combinations for common AWG sizes (11 - 26.5, including half sizes) and standard metric sizes (1.8 to 0.67 mm) that make it easy to determine a variety of wire combinations that meet a target area.

To use Table 1, 2 or 3, find the combination (1, 1 + 1, 2, 2 + 1, etc.) in the Parallels (left-most) column and then scan that row from left to right to get the circular mil area for the corresponding wire size(s). You can also scroll down wire size columns to find combinations for the CM area that is closest to the calculated target area. In Table 1,for example, the row for 1 parallel with #13 AWG wire shows a CM area of 5178. The row for parallels of 1 + 1 for sizes #13 and #14 AWG shows an area of 9285 CM.

Note that for combinations with two or more parallels the first number represents the larger AWG or metric size, and the second number represents the next smaller size. Thus, to find the CM area for 4 #17 AWG + 1 #18 AWG, you would scroll down the Parallels column to the row for 4 + 1, and then scan to the right until you reach the data between the #16 and #17 AWG sizes: 12379 CM.

TABLE 6-1: ROUND WIRE COMBINATIONS – AWG SIZES 13 - 28*

***CROSS-SECTIONAL AREAS IN CIRCULAR MILS (1 MM^2 → 1974 CM → 0.00155 IN^2)**

Parallels	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	5178	4107	3257	2583	2048	1624	1288	1022	810	642	509	404	320	254	202	
1 + 1	9285	7364	5840	4631	3673	2912	2310	1832	1453	1152	914	724	575	456	361	
2	10357	8213	6514	5165	4096	3249	2576	2043	1620	1285	1019	808	641	508	403	
1 + 2	13392	10620	8422	6679	5297	4201	3331	2642	2095	1661	1318	1045	829	657	521	
2 + 1	14464	11470	9096	7214	5721	4537	3598	2853	2263	1794	1423	1128	895	710	563	
3	15535	12320	9770	7748	6145	4873	3864	3065	2430	1927	1528	1212	961	762	605	
1 + 3	17499	13877	11005	8727	6921	5489	4353	3452	2737	2171	1722	1365	1083	859	681	
2 + 2	18570	14727	11679	9262	7345	5825	4619	3663	2905	2304	1827	1449	1149	911	723	
3 + 1	19642	15577	12353	9796	7769	6161	4886	3875	3073	2437	1932	1533	1215	964	764	
4	20714	16427	13027	10331	8193	6497	5153	4086	3240	2570	2038	1616	1282	1016	806	
1 + 4	21605	17134	13588	10776	8545	6777	5374	4262	3380	2680	2126	1686	1337	1060	841	
2 + 3	22677	17984	14262	11310	8969	7113	5641	4473	3548	2813	2231	1769	1403	1113	882	
3 + 2	23749	18834	14936	11845	9393	7449	5907	4685	3715	2946	2337	1853	1469	1165	924	
4 + 1	24821	19684	15610	12379	9817	7785	6174	4896	3883	3079	2442	1937	1536	1218	966	
1 + 5	25712	20391	16171	12824	10170	8065	6396	5072	4022	3190	2530	2006	1591	1262	1001	
5	25892	20534	16284	12914	10241	8122	6441	5108	4051	3212	2547	2020	1602	1271	1008	
2 + 4	26784	21241	16845	13358	10594	8401	6662	5284	4190	3323	2635	2090	1657	1314	1042	
3 + 3	27856	22091	17519	13893	11018	8737	6929	5495	4358	3456	2741	2173	1724	1367	1084	
4 + 2	28927	22940	18193	14427	11441	9073	7196	5706	4525	3589	2846	2257	1790	1419	1126	
1 + 6	29819	23647	18753	14872	11794	9353	7417	5882	4665	3699	2934	2327	1845	1463	1160	
5 + 1	29999	23790	18867	14962	11865	9410	7462	5918	4693	3722	2951	2341	1856	1472	1167	
2 + 5	30891	24497	19427	15407	12218	9689	7684	6094	4832	3832	3039	2410	1911	1516	1202	
6	31071	24640	19541	15496	12289	9746	7729	6129	4861	3855	3057	2424	1923	1525	1209	
3 + 4	31962	25347	20101	15941	12642	10025	7951	6305	5000	3965	3145	2494	1978	1568	1244	
4 + 3	33034	26197	20775	16476	13066	10362	8217	6516	5168	4098	3250	2577	2044	1621	1285	
1 + 7	33926	26904	21336	16920	13418	10641	8439	6692	5307	4209	3338	2647	2099	1665	1320	
5 + 2	34106	27047	21449	17010	13490	10698	8484	6728	5335	4231	3356	2661	2110	1674	1327	
2 + 6	34997	27754	22010	17455	13842	10977	8705	6904	5475	4342	3443	2731	2165	1717	1362	
6 + 1	35178	27897	22123	17545	13914	11034	8750	6939	5503	4364	3461	2745	2177	1726	1369	
3 + 5	36069	28604	22684	17989	14266	11314	8972	7115	5643	4475	3549	2814	2232	1770	1404	
7	36249	28747	22797	18079	14337	11370	9017	7151	5671	4497	3566	2828	2243	1779	1411	
4 + 4	37141	29454	23358	18524	14690	11650	9239	7327	5810	4608	3654	2898	2298	1822	1445	

EXAMPLES

The following examples illustrate the benefits of using a combination table when making wire size changes manually.

Example 1

A stator is being rewound that has 8 turns per coil of 1 #15 AWG + 3 #16 AWG conductors. No changes are needed, but the service center is out of #15 AWG. The new target turn area is calculated using Table 6-1:

$A_2 = A_1 \cdot T_1 / T_2 \rightarrow A_2 = 11005 \cdot 8 / 8 = 11005$ CM

The winder doesn't want to use anything larger in area than a #16 AWG, so starting with #16 AWG, he scrolls down looking for numbers preferably equal to or slightly greater than 11005 CM. In just a few seconds, he finds several combinations that he can easily evaluate by dividing A_2 by A_1. See Example 1 Table below.

Example 1 Table

Combination	Area	A_2 / A_1(% Change)
2#16 AWG + 3#17 AWG	11310 CM	1.0277 (+2.77%)
3#17 AWG + 3#18 AWG	11018 CM	1.0011 (+0.11%)
6#18 AWG + 1#19 AWG	11034 CM	1.0026 (+0.26%)

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Example 2

A stator is being rewound that has 10 turns per coil of 2 #19 AWG + 5 #20 AWG conductors. The service center is redesigning the machine from a 1Y connection to a 1YD connection to facilitate a YD starter their customer is installing, and the new coil will have 17 turns. The new target turn area is calculated using Table 6-1:

$A_2 = A_1 \bullet T_1 / T_2 \rightarrow A_1 = 7684 \bullet 10 / 17 = 4520$ CM

The winder doesn't want to use anything larger in area than a #19 AWG, so starting with #19 AWG he scrolls down looking for numbers preferably equal to or slightly greater than 4520 CM. In just a few seconds, he finds several combinations that he can easily evaluate by dividing A_2 by A_1. See Example 2 Table below.

Example 2 Table

Combination	Area	A_2 / A_1(% Change)
2#19 AWG + 2#20 AWG	4619 CM	1.0219 (+2.19%)
2#20 AWG + 3#21 AWG	4473 CM	0.9896 (-1.04%)
4#21 AWG + 2#22 AWG	4525 CM	1.0011 (+0.11%)

Example 3

A stator is being rewound that has 11 turns per coil of 2 #18 AWG conductors. The service center is redesigning the machine from a 575V to 208V, and the new coil will have 4 turns. The new target turn area is calculated using Table 6-1:

$A_2 = A_1 \bullet T_1 / T_2 \rightarrow A_2 = 3249 \bullet 11 / 4 = 8935$ CM

The winder doesn't want to use anything larger in area than a #17 AWG, so starting with #17 AWG he scrolls down looking for numbers preferably equal to or slightly greater than 8935 CM. In just a few seconds, he finds several combinations that he can easily evaluate by dividing A_2 by A_1. See Example 3 Table below.

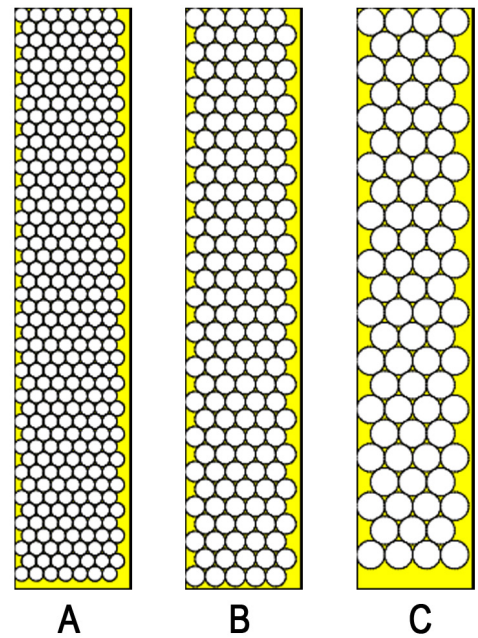
Example 3 Table

Combination	Area	A_2 / A_1(% Change)
2#17 AWG + 3#18 AWG	8969 CM	1.0038 (+0.38%)
4#18 AWG + 2#19 AWG	9073 CM	1.0154 (+1.54%)
7#19 AWG + 5#20 AWG	9017 CM	1.0092 (+0.92%)

There are multiple factors that determine which wire sizes will provide the best overall slot fill for a particular machine. Smaller diameters tend to nest better, but given the minimum insulation thickness requirements, the portion of a conductor's cross-sectional area that consists of copper significantly decreases as the diameter decreases. A circle packing software tool was used to produce the graphic shown in Figure 6-2 that represents a 0.25 X 1.25 stator slot with insulated conductor diameters of (A) 0.031, (B) 0.043 and (C) 0.060 (unitless).

While this is an atypical slot geometry for most random-wound machines, the net percentage of the slot filled with copper for each of the three sizes is within 3% of the average. The diametrical spread used is representative of a range consisting of 6 AWG sizes (e.g., #15 AWG - #21 AWG). This indicates that picking combinations that contain ± a couple of AWG sizes should not have a significant impact on the winder's ability to replace the stator winding, providing the slot is insulated similarly and the conductor area used is close to the calculated value as previously described and illustrated by example. Since smaller spaces tend to retain varnish or resin better, design (A) may have some thermal advantages over design (C).

FIGURE 6-2



Slot fill and conductor size.

Another consideration is dielectric strength, since the minimum standard allowable insulation thickness tends to decrease as the diameter decreases. For example, one might consider using either 1 #16 AWG or 2 #19 AWG in a particular design. The 2 #19 might nest better, but the minimum insulation thickness allowed by NEMA MW-1000 for #19 AWG is 14% less than that allowed for #16 AWG. This results in a similar reduction in minimum dielectric strength.

In summary, even though service centers are encouraged to use a software tool for winding data verification and redesign activities, there are certainly times when a winder may not have this option. In these cases, using tools such as the combination tables presented here for straightforward changes can save valuable time while preventing errors.

Note: This artcle was originally published in *EASA Currents* (April 2015). It was reviewed and updated as necessary in October 2020.

TABLE 2: ROUND WIRE COMBINATIONS – AWG SIZES 11 - 26.5*

***CROSS-SECTIONAL AREAS IN CIRCULAR MILS (1 MM^2 → 1974 CM → 0.00155 IN^2)**

Parallels	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5
1	8234	7333	6530	5815	5178	4612	4107	3657	3257	2900	2583	2300	2048	1824	1624	
1 + 1	15567	13863	12345	10994	9790	8718	7764	6914	6157	5483	4883	4348	3872	3448	3071	
2	16468	14665	13060	11630	10357	9223	8213	7314	6514	5800	5165	4600	4096	3648	3249	
1 + 2	22899	20393	18160	16172	14402	12825	11421	10171	9057	8066	7183	6396	5696	5073	4517	
2 + 1	23801	21195	18875	16809	14969	13330	11871	10571	9414	8383	7465	6648	5920	5272	4695	
3	24702	21998	19590	17445	15535	13835	12320	10971	9770	8701	7748	6900	6145	5472	4873	
1 + 3	30232	26923	23975	21351	19013	16932	15078	13427	11958	10648	9483	8445	7520	6697	5964	
2 + 2	31134	27725	24690	21987	19580	17437	15528	13828	12314	10966	9765	8696	7744	6897	6142	
3 + 1	32035	28528	25405	22624	20147	17941	15977	14228	12671	11283	10048	8948	7969	7096	6319	
4	32936	29331	26120	23260	20714	18446	16427	14629	13027	11601	10331	9200	8193	7296	6497	
1 + 4	37565	33452	29790	26529	23625	21038	18735	16684	14858	13231	11783	10493	9344	8321	7410	
2 + 3	38466	34255	30505	27166	24192	21543	19185	17085	15214	13549	12065	10745	9568	8521	7588	
3 + 2	39368	35058	31220	27802	24759	22048	19634	17485	15571	13866	12348	10996	9793	8721	7766	
4 + 1	40269	35861	31935	28439	25326	22553	20084	17885	15927	14184	12631	11248	10017	8920	7944	
1 + 5	44898	39982	35605	31708	28236	25145	22392	19941	17758	15814	14083	12541	11168	9946	8857	
5	41171	36663	32650	29075	25892	23058	20534	18286	16284	14501	12914	11500	10241	9120	8122	
2 + 4	45799	40785	36320	32344	28803	25650	22842	20341	18115	16131	14365	12793	11392	10145	9035	
3 + 3	46700	41588	37035	32981	29370	26155	23292	20742	18471	16449	14648	13045	11617	10345	9212	
4 + 2	47602	42391	37750	33617	29937	26660	23741	21142	18828	16766	14931	13296	11841	10545	9390	
1 + 6	52230	46512	41420	36886	32848	29252	26050	23198	20658	18397	16383	14589	12992	11570	10303	
5 + 1	48503	43193	38465	34254	30504	27165	24191	21542	19184	17084	15214	13548	12065	10744	9568	
2 + 5	53132	47315	42135	37523	33415	29757	26499	23598	21015	18714	16665	14841	13216	11769	10481	
6	49405	43996	39180	34891	31071	27669	24640	21943	19541	17401	15496	13800	12289	10944	9746	
3 + 4	54033	48118	42850	38159	33982	30262	26949	23999	21371	19032	16948	15093	13441	11969	10659	
4 + 3	54935	48921	43565	38796	34549	30766	27398	24399	21728	19349	17231	15345	13665	12169	10837	
1 + 7	59563	53042	47236	42064	37459	33359	29707	26455	23559	20979	18683	16637	14816	13194	11750	
5 + 2	55836	49723	44280	39432	35116	31271	27848	24799	22084	19667	17514	15596	13889	12369	11014	
2 + 6	60464	53845	47950	42701	38026	33863	30156	26855	23915	21297	18965	16889	15040	13394	11928	
6 + 1	56737	50526	44995	40069	35682	31776	28297	25200	22441	19984	17796	15848	14113	12568	11192	
3 + 5	61366	54648	48665	43338	38593	34368	30606	27255	24272	21614	19248	17141	15265	13593	12105	
7	57639	51329	45710	40706	36249	32281	28747	25600	22797	20302	18079	16100	14337	12768	11370	
4 + 4	62267	55451	49380	43974	39160	34873	31055	27656	24628	21932	19531	17393	15489	13793	12283	

(Continues on next page.)

To find acceptable equivalent wire size combinations:

Scroll down the Parallels column to the appropriate combination (1, 1 + 1, 2, 2 + 1, etc.).

Scan that row to find the circular mil area closest to the calculated target area per turn and the acceptable equivalent wire size combinations. For example, the row for 1 parallel with #11 AWG wire shows a CM area of 8234. For parallels of 1 + 1 with a combination of #11 and #11.5 AWG wire sizes, the cross-sectional area per turn would be 15567 CM.

With two or more parallels, the first number represents the larger wire size; the second number represents the next smaller size.

The unit for the conductor area does not matter but must be consistent with available materials and familiar to the technician. The circular mil (CM) is used here, but the square inch (in^2) or square millimeter (mm^2) are equally correct, providing units are used consistently (1 mm^2 → 1974 CM → 0.00155 in^2).

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TABLE 2: ROUND WIRE COMBINATIONS – AWG SIZES 11 - 26.5–CONTINUED*

***CROSS-SECTIONAL AREAS IN CIRCULAR MILS (1 MM^2 → 1974 CM → 0.00155 IN^2)**

Parallels	19	19.5	20	20.5	21	21.5	22	22.5	23	23.5	24	24.5	25	25.5	26	26.5
1	1288	1147	1022	910	810	721	642	572	509	454	404	360	320	285	254	
1 + 1	2435	2169	1931	1720	1532	1364	1215	1082	963	858	764	680	606	539	480	
2	2576	2294	2043	1819	1620	1443	1285	1144	1019	907	808	720	641	571	508	
1 + 2	3582	3190	2841	2530	2253	2006	1787	1591	1417	1262	1124	1001	891	794	707	
2 + 1	3723	3316	2953	2630	2342	2085	1857	1654	1473	1311	1168	1040	926	825	734	
3	3864	3441	3065	2729	2430	2164	1927	1716	1528	1361	1212	1079	961	856	762	
1 + 3	4729	4212	3751	3340	2974	2649	2359	2101	1871	1666	1483	1321	1176	1048	933	
2 + 2	4870	4337	3862	3440	3063	2728	2429	2163	1926	1716	1528	1360	1212	1079	961	
3 + 1	5012	4463	3974	3539	3152	2807	2499	2226	1982	1765	1572	1400	1247	1110	989	
4	5153	4588	4086	3639	3240	2886	2570	2288	2038	1815	1616	1439	1282	1141	1016	
1 + 4	5877	5233	4660	4150	3696	3291	2931	2610	2324	2070	1843	1641	1462	1302	1159	
2 + 3	6018	5359	4772	4250	3785	3370	3001	2673	2380	2120	1888	1681	1497	1333	1187	
3 + 2	6159	5484	4884	4349	3873	3449	3072	2735	2436	2169	1932	1720	1532	1364	1215	
4 + 1	6300	5610	4996	4449	3962	3528	3142	2798	2492	2219	1976	1760	1567	1395	1243	
1 + 5	7024	6255	5570	4960	4417	3934	3503	3120	2778	2474	2203	1962	1747	1556	1386	
5	6441	5736	5108	4549	4051	3607	3212	2861	2547	2269	2020	1799	1602	1427	1271	
2 + 4	7165	6380	5682	5060	4506	4013	3573	3182	2834	2524	2247	2001	1782	1587	1413	
3 + 3	7306	6506	5794	5159	4595	4092	3644	3245	2890	2573	2292	2041	1817	1618	1441	
4 + 2	7447	6632	5906	5259	4683	4171	3714	3307	2945	2623	2336	2080	1852	1650	1469	
1 + 6	8171	7276	6480	5770	5139	4576	4075	3629	3232	2878	2563	2282	2032	1810	1612	
5 + 1	7588	6757	6017	5359	4772	4250	3784	3370	3001	2673	2380	2119	1887	1681	1497	
2 + 5	8312	7402	6592	5870	5227	4655	4145	3692	3288	2928	2607	2322	2068	1841	1640	
6	7729	6883	6129	5458	4861	4329	3855	3433	3057	2722	2424	2159	1923	1712	1525	
3 + 4	8453	7527	6703	5970	5316	4734	4216	3754	3343	2977	2651	2361	2103	1872	1667	
4 + 3	8594	7653	6815	6069	5405	4813	4286	3817	3399	3027	2696	2400	2138	1904	1695	
1 + 7	9318	8298	7389	6580	5860	5219	4647	4139	3685	3282	2923	2603	2318	2064	1838	
5 + 2	8735	7779	6927	6169	5493	4892	4356	3880	3455	3077	2740	2440	2173	1935	1723	
2 + 6	9459	8423	7501	6680	5949	5298	4718	4201	3741	3332	2967	2642	2353	2095	1866	
6 + 1	8876	7904	7039	6268	5582	4971	4427	3942	3511	3126	2784	2479	2208	1966	1751	
3 + 5	9600	8549	7613	6780	6037	5377	4788	4264	3797	3381	3011	2682	2388	2127	1894	
7	9017	8030	7151	6368	5671	5050	4497	4005	3566	3176	2828	2519	2243	1997	1779	
4 + 4	9741	8675	7725	6879	6126	5456	4858	4326	3853	3431	3055	2721	2423	2158	1922	

TABLE 3: ROUND WIRE COMBINATIONS – METRIC SIZES 1.8 - 0.67 MM*

***CROSS-SECTIONAL AREAS IN CIRCULAR MILS (1 MM^2 → 1974 CM → 0.00155 IN^2)**

Parallels	1.8	1.5	1.4	1.32	1.25	1.18	1.12	1.06	1.0	0.95	0.9	0.85	0.8	0.75	0.67	0.63
1	5022	3488	3038	2701	2422	2158	1944	1742	1550	1399	1256	1120	992	872	696	
1 + 1	8510	6526	5739	5123	4580	4103	3686	3292	2949	2654	2375	2112	1864	1568	1311	
2	10044	6975	6076	5401	4844	4316	3889	3483	3100	2798	2511	2240	1984	1744	1392	
1 + 2	11997	9564	8439	7544	6738	6047	5427	4842	4348	3910	3495	3104	2736	2263	1926	
2 + 1	13532	10013	8777	7823	7002	6261	5630	5033	4499	4053	3631	3232	2856	2440	2007	
3	15066	10463	9114	8102	7266	6475	5833	5225	4650	4197	3767	3360	2976	2616	2087	
1 + 3	15485	12602	11140	9966	8897	7991	7169	6392	5747	5165	4615	4096	3608	2959	2541	
2 + 2	17019	13051	11477	10245	9160	8205	7372	6583	5898	5309	4751	4224	3728	3135	2622	
3 + 1	18554	13501	11815	10524	9424	8419	7575	6775	6049	5452	4886	4352	3848	3311	2703	
4	20088	13950	12152	10803	9688	8633	7777	6966	6200	5596	5022	4480	3968	3488	2783	
1 + 4	18972	15640	13841	12388	11055	9936	8911	7942	7146	6421	5735	5088	4480	3655	3157	
2 + 3	20507	16089	14178	12667	11318	10149	9113	8133	7297	6564	5871	5216	4600	3831	3237	
3 + 2	22041	16539	14515	12946	11582	10363	9316	8325	7448	6708	6006	5344	4720	4007	3318	
4 + 1	23576	16988	14853	13225	11846	10577	9519	8516	7599	6851	6142	5472	4840	4183	3398	
1 + 5	22460	18678	16542	14810	13213	11880	10652	9492	8544	7676	6855	6080	5351	4351	3772	
5	25110	17438	15190	13504	12109	10791	9722	8708	7750	6994	6278	5599	4960	4359	3479	
2 + 4	23994	19127	16879	15089	13477	12094	10855	9683	8696	7820	6991	6208	5472	4527	3852	
3 + 3	25529	19577	17216	15368	13740	12308	11058	9875	8847	7963	7126	6336	5592	4703	3933	
4 + 2	27063	20026	17553	15647	14004	12522	11260	10066	8998	8107	7262	6464	5712	4879	4014	
1 + 6	25947	21716	19242	17232	15371	13824	12394	11042	9943	8932	7975	7072	6223	5047	4387	
5 + 1	28598	20476	17891	15926	14268	12735	11463	10258	9149	8250	7397	6591	5832	5055	4094	
2 + 5	27482	22165	19580	17511	15635	14038	12597	11233	10094	9075	8110	7200	6343	5223	4468	
6	30132	20925	18228	16204	14531	12949	11666	10449	9300	8393	7533	6719	5952	5231	4175	
3 + 4	29016	22615	19917	17790	15899	14252	12799	11425	10246	9219	8246	7328	6464	5399	4548	
4 + 3	30551	23064	20254	18069	16162	14466	13002	11616	10397	9362	8382	7456	6584	5575	4629	
1 + 7	29435	24754	21943	19654	17529	15768	14135	12592	11342	10187	9095	8064	7095	5742	5002	
5 + 2	32085	23514	20591	18347	16426	14680	13205	11808	10548	9505	8517	7583	6704	5751	4709	
2 + 6	30969	25203	22280	19933	17793	15982	14338	12783	11493	10331	9230	8192	7215	5919	5083	
6 + 1	33620	23963	20929	18626	16690	14894	13408	12000	10699	9649	8653	7711	6824	5927	4790	
3 + 5	32504	25653	22618	20212	18057	16196	14541	12975	11644	10474	9366	8320	7335	6095	5163	
7	35154	24413	21266	18905	16953	15108	13610	12191	10850	9792	8789	7839	6944	6103	4871	
4 + 4	34038	26102	22955	20490	18320	16410	14744	13166	11796	10618	9502	8448	7456	6271	5244	

To find acceptable equivalent wire size combinations:

- Scroll down the Parallels column to the appropriate combination (1, 1 + 1, 2, 2 + 1, etc.).
- Scan that row to find the circular mil area closest to the calculated target area per turn and the acceptable equivalent wire size combinations. For example, the row for 1 parallel with 1.8 mm wire shows a CM area of 5022. For parallels of 1 + 1 with a combination of 1.8 mm and 1.5 mm wire sizes, the cross-sectional area per turn would be 8510 CM.
- With two or more parallels, the first number represents the larger wire size; the second number represents the next smaller size.
- The unit for the conductor area does not matter but must be consistent with available materials and familiar to the technician. The circular mil (CM) is used here, but the square inch (in^2) or square millimeter (mm^2) are equally correct, providing units are used consistently (1 mm^2 → 1974 CM → 0.00155 in^2).

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SQUARE BARE COPPER WIRE DATA—AWG SIZES

NOMINAL DATA

SIZE	DIMENSION	AREA		WEIGHT		DC RESISTANCE*	
AWG	INCHES	CIRCULAR MILS	SQUARE MM	LBS PER 1000 FT	FEET PER LB	OHMS PER 1000 FT	OHMS PER LB
0000	0.4600	259700	131.627	786.1	1.272	0.03993	0.0000508
000	0.4096	211900	107.400	641.4	1.559	0.04894	0.0000763
00	0.3648	167700	84.997	507.6	1.970	0.06184	0.0001218
00.5	0.3443	149200	75.621	451.6	2.214	0.06951	0.0001539
0	0.3249	132700	67.258	401.7	2.490	0.07815	0.0001946
0.5	0.3066	117900	59.757	356.9	2.802	0.08796	0.0002465
1	0.2893	104810	53.122	317.3	3.152	0.09895	0.0003119
1.5	0.2730	93140	47.207	281.9	3.547	0.1113	0.0003949
2	0.2576	82740	41.936	250.5	3.993	0.1253	0.0005005
2.5	0.2431	73490	37.248	222.5	4.495	0.1411	0.0006344
3	0.2294	65250	33.071	197.5	5.063	0.1589	0.0008047
3.5	0.2165	57930	29.361	175.4	5.703	0.1790	0.001021
4	0.2043	51400	26.052	155.6	6.427	0.2018	0.001297
4.5	0.1928	45590	23.107	138.0	7.246	0.2275	0.001648
5	0.1819	40380	20.466	122.2	8.181	0.2568	0.002101
5.5	0.1717	35780	18.135	108.3	9.233	0.2899	0.002676
6	0.1620	32310	16.376	97.80	10.22	0.3210	0.003282
6.5	0.1529	28660	14.526	86.75	11.53	0.3619	0.004171
7	0.1443	25390	12.869	76.86	13.01	0.4085	0.005315
7.5	0.1362	22500	11.404	68.11	14.68	0.4609	0.006768
8	0.1285	19900	10.086	60.24	16.60	0.5212	0.008651
8.5	0.1213	17990	9.118	54.46	18.36	0.5765	0.01059
9	0.1144	15930	8.074	48.22	20.74	0.6510	0.01350
9.5	0.1080	14110	7.152	42.71	23.41	0.7350	0.01721
10	0.1019	12480	6.325	37.78	26.47	0.8310	0.02200
10.5	0.0962	11040	5.596	33.42	29.92	0.9394	0.02811
11	0.0907	10030	5.084	30.36	32.94	0.103	0.03406
11.5	0.0856	8890	4.506	26.92	37.15	1.166	0.04333
12	0.0808	7880	3.994	23.84	41.95	1.317	0.05525
12.5	0.0763	6980	3.538	21.11	47.36	1.487	0.07042
13	0.0720	6320	3.203	19.13	52.26	1.641	0.08575
13.5	0.0679	5590	2.833	16.92	59.10	1.855	0.1096
14	0.0641	4950	2.509	14.99	66.71	2.094	0.1397
14.5	0.0605	4380	2.220	13.26	75.42	2.368	0.1786
15	0.0571	3870	1.961	11.72	85.32	2.678	0.2285
15.5	0.0539	3420	1.733	10.35	96.60	3.032	0.2929
16	0.0508	3010	1.526	9.099	109.9	3.450	0.3792

* Resistance values based on copper of 100% conductivity at 20°C (68°F).

RECTANGULAR WIRE—CIRCULAR MIL AREA*

WIDTH INCHES (MM)	THICKNESS – INCHES (MM)																	WIDTH INCHES (MM)
	0.040 (1.02)	0.045 (1.14)	0.051 (1.30)	0.057 (1.45)	0.064 (1.63)	0.072 (1.83)	0.081 (2.06)	0.091 (2.31)	0.102 (2.59)	0.114 (2.90)	0.128 (3.25)	0.144 (3.66)	0.162 (4.11)	0.182 (4.62)	0.204 (5.18)	0.229 (5.82)	0.258 (6.55)	
0.091 (2.31)		4661	5200	5715	6977	7906	8946											0.091 (2.31)
0.096 (2.44)		4946	5524	6079	7387	8365	9465											0.096 (2.44)
0.102 (2.59)	4757	5293	5914	6515	7876	8913	10080	11380										0.102 (2.59)
0.108 (2.74)	5065	5636	6303	6951	8365	9465	10700	12070										0.108 (2.74)
0.114 (2.90)	5368	5980	6693	7387	8854	10010	11320	12770	14070									0.114 (2.90)
0.121 (3.07)	5725	6379	7146	7892	9422	10650	12040	13580	14980									0.121 (3.07)
0.128 (3.25)	6082	6779	7602	8401	9994	11300	12760	14390	15880	17840								0.128 (3.25)
0.136 (3.45)	6488	7238	8120	8983	10640	12030	13590	15320	16920	19000								0.136 (3.45)
0.144 (3.66)	6898	7698	8639	9564	11300	12760	14410	16250	17960	20160	22420							0.144 (3.66)
0.153 (3.89)	7354	8213	9224	10210	12030	13590	15340	17290	19130	21470	23890							0.153 (3.89)
0.162 (4.11)	7813	8728	9809	10870	12760	14410	16270	18330	20300	22780	25350	28650						0.162 (4.11)
0.172 (4.37)	8322	9303	10460	11600	13580	15330	17300	19490	21600	24230	26980	30490						0.172 (4.37)
0.182 (4.62)	8831	9875	11110	12320	14390	16250	18330	20650	22900	25680	28610	32320	36510					0.182 (4.62)
0.193 (4.90)	9392	10510	11820	13120	14680	16640	18850	21310	24010	26960	30400	34330	38750					0.193 (4.90)
0.204 (5.18)	9954	11130	12540	13920	15570	17650	19990	22590	25440	28560	32200	36340	41030	45620				0.204 (5.18)
0.217 (5.51)	10610	11880	13380	14860	16630	18840	21330	24090	27130	30450	34330	38750	43710	48630				0.217 (5.51)
0.229 (5.82)	11230	12570	14160	15730	17610	19940	22570	25480	28690	32190	36270	40930	46190	51410	57810			0.229 (5.82)
0.243 (6.17)	11940	13370	15070	16750	18750	21230	24010	27100	30510	34230	38550	43510	49060	54640	61450			0.243 (6.17)
0.258 (6.55)	12700	14230	16040	17840	19970	22600	25560	28840	32460	36410	41000	46250	52170	58110	65350	73570		0.258 (6.55)
0.273 (6.93)	13470	15090	17020	18920	21200	23970	27100	30580	34390	38590	43440	48990	55270	61610	69250	77930		0.273 (6.93)
0.289 (7.34)	14280	16010	18050	20090	22500	25440	28760	32440	36470	40900	46050	51930	58570	65310	73410	82590	93260	0.289 (7.34)

* This table was adapted from NEMA Std. MW 1000: *Magnet Wire*, Table 1-13: Increase in Dimensions for Glass Fiber Covered Rectangular Magnet Wire.

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RECTANGULAR WIRE—CIRCULAR MIL AREA* (Continued)

WIDTH INCHES (MM)	THICKNESS – INCHES (MM)																	WIDTH INCHES (MM)
	0.040 (1.02)	0.045 (1.14)	0.051 (1.30)	0.057 (1.45)	0.064 (1.63)	0.072 (1.83)	0.081 (2.06)	0.091 (2.31)	0.102 (2.59)	0.114 (2.90)	0.128 (3.25)	0.144 (3.66)	0.162 (4.11)	0.182 (4.62)	0.204 (5.18)	0.229 (5.82)	0.258 (6.55)	
0.307 (7.80)	15200	17040	19220	21390	23960	27090	30610	34520	38820	43510	48990	55240	62270	69480	78070	87840	99180	0.307 (7.80)
0.325 (8.26)	16120	18070	20390	22700	25430	28740	32470	36600	41160	46120	51900	58540	65970	73640	82760	93100	105100	0.325 (8.26)
0.344 (8.74)	17080	19160	21630	24080	26980	30490	34420	38820	43610	48890	55010	62010	69910	78070	87680	98650	111300	0.344 (8.74)
0.365 (9.27)	18150	20360	22990	25600	28690	32410	36600	41230	46350	51930	58440	65880	74230	82920	93130	104800	118200	0.365 (9.27)
0.387 (9.83)	19270	21620	24420	27200	30490	34420	38850	43770	49220	55140	62010	69910	78760	88010	98850	111200	125500	0.387 (9.83)
0.410 (10.41)		22940	25910	28870	32360	36540	41230	46450	52200	58480	65780	74130	83520	93360	104800	117900	133000	0.410 (10.41)
0.434 (11.02)		24310	27470	30610	34330	38750	43710	49220	55300	61940	69670	78530	88470	98910	111100	124900	140900	0.434 (11.02)
0.460 (11.68)			29160	32500	36440	41130	46380	52230	58710	65710	73900	83290	93820	104900	117800	132400	149500	0.460 (11.68)
0.487 (12.37)			30910	34460	38620	43610	49160	55370	62210	69640	78330	88240	99410	111200	124800	140300	158300	0.487 (12.37)
0.517 (13.13)				36640	41060	46350	52260	58840	66110	74000	83220	93730	105600	118100	132600	149100	168200	0.517 (13.13)

* This table was adapted from NEMA Std. MW 1000: *Magnet Wire*, Table 1-13: Increase in Dimensions for Glass Fiber Covered Rectangular Magnet Wire.

RECTANGULAR WIRE—METRIC SIZES AND CROSS-SECTIONAL AREA

Width (mm)		Thickness (mm)																												Width (mm)	
R 10		0.50		0.63		0.80		1.00		1.25		1.60		2.00		2.50		3.15		4.00		5.00		6.30		8.00		10.00			R 10
	R 20		0.56		0.71		0.90		1.12		1.40		1.80		2.24		2.80		3.55		4.50		5.60		7.10		9.00		R 20		
		mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²		
12.5		6.196	6.933	7.790	8.767	9.863	11.08	12.29	13.79	15.41	17.29	19.79	22.14	24.64	27.64	30.70	34.45	38.83	43.83	49.14	55.39	61.64	69.14	77.89	87.89	99.14	111.6				12.5
	14.0		7.773	8.735	9.832	11.06	12.43	13.79	15.47	17.29	19.39	22.19	24.84	27.64	31.00	34.45	38.65	43.55	49.15	55.14	62.14	69.14	77.54	87.34	98.54	111.1	125.1	139.1	14.0		
16.0				9.995	11.25	12.66	14.23	15.79	17.71	19.79	22.19	25.39	28.44	31.64	35.48	39.45	44.25	49.85	56.25	63.14	71.14	79.14	88.74	99.94	112.7	127.1	143.1	159.1			16.0
	18.0				12.67	14.26	16.03	17.79	19.95	22.29	24.99	28.59	32.04	35.64	39.96	44.45	49.85	56.15	63.35	71.14	80.14	89.14	99.94	112.5	126.9	143.1	161.1	179.1	18.0		
20.0						15.86	17.83	19.79	22.19	24.79	27.79	31.79	35.64	39.64	44.44	49.45	55.45	62.45	70.45	79.14	89.14	99.14	111.1	125.1	141.1	159.1	179.1	199.1			20.0
	22.4					17.78	19.99	22.19	24.87	27.79	31.15	35.63	39.96	44.44	49.81	55.45	62.17	70.01	78.97	88.74	99.94	111.1	124.9	140.3	158.2	178.3	200.7	223.1	22.4		
25.0						19.86	22.23	24.79	27.79	31.04	34.79	39.79	44.64	49.64	55.64	61.95	69.45	78.20	88.20	99.14	111.6	124.1	139.1	156.6	176.6	199.1	224.1	249.1			25.0
	28.0					22.26	25.03	27.79	31.15	34.79	38.99	44.59	50.04	55.64	62.36	69.45	77.85	87.65	98.85	111.1	125.1	139.1	155.9	175.5	197.9	223.1	251.1	279.1	28.0		
31.5						25.06	28.18	31.29	35.07	39.16	43.89	50.19	56.34	62.64	70.20	78.20	87.65	98.68	111.3	125.1	140.9	156.6	175.5	197.6	222.8	251.1	282.6	314.1			31.5
	35.5					28.26	31.78	35.29	39.55	44.16	49.49	56.59	63.54	70.64	79.16	88.20	98.85	111.3	125.5	141.1	158.9	176.6	197.9	222.8	251.2	283.1	318.6	354.1	35.5		
40.0						31.86	35.83	39.79	44.59	49.79	55.79	63.79	71.64	79.64	89.24	99.45	111.5	125.5	141.5	159.1	179.1	199.1	223.1	251.1	283.1	319.1	359.1	399.1			40.0
	45.0					35.86	40.33	44.79	50.19	56.04	62.79	71.79	80.64	89.64	100.4	112.0	125.5	141.2	159.2	179.1	201.6	224.1	251.1	282.6	318.6	359.1	404.1	449.1	45.0		
50.0						39.86	44.83	49.79	55.79	62.29	69.79	79.79	89.64	99.64	111.6	124.5	139.5	157.0	177.0	199.1	224.1	249.1	279.1	314.1	354.1	399.1	449.1	499.1			50.0

Width (mm)		Thickness (mm)																												Width (mm)	
R" 10		0.5		0.6		0.8		1.0		1.2		1.6		2.0		2.5		3.0		4.0		5.0		6.0		8.0		10.0			R" 10
	R" 20		0.55		0.7		0.9		1.1		1.4		1.8		2.2		2.8		3.5		4.5		5.5		7.0		9.0		R" 20		
						mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²			
	55					43.86	49.33	54.79	60.29	65.79	76.79	87.79	98.64	109.6	120.6	137.0	153.5	164.5	192.0	219.1	246.6	274.1	301.6	329.1	384.1	439.1	494.1	549.1	55		
60						47.86	53.83	59.79	65.79	71.79	83.79	95.79	107.6	119.6	131.6	149.5	167.5	179.5	209.5	239.1	269.1	299.1	329.1	359.1	419.1	479.1	539.1	599.1			60
	70					55.86	62.83	69.79	76.79	83.79	97.79	111.8	125.6	139.6	153.6	174.5	195.5	209.5	244.5	279.1	314.1	349.1	384.1	419.1	489.1	559.1	629.1	699.1	70		
80						63.86	71.83	79.79	87.79	95.79	111.8	127.8	143.6	159.6	175.6	199.5	223.5	239.5	279.5	319.1	359.1	399.1	439.1	479.1	559.1	639.1	719.1	799.1			80
	90						80.83	89.79	98.79	107.8	125.8	143.8	161.6	179.6	197.6	224.5	251.5	269.5	314.5	359.1	404.1	449.1	494.1	539.1	629.1	719.1	809.1	899.1	90		
100								99.79	109.8	119.8	139.8	159.8	179.6	199.6	219.6	249.5	279.5	299.5	349.5	399.1	449.1	499.1	549.1	599.1	699.1	799.1	899.1	999.1			100
	110																		384.5	439.1	494.1	549.1	604.1	659.1	769.1	879.1	989.1	1099	110		
120																				479.1	539.1	599.1	659.1	719.1	839.1	959.1	1079	1199			120
Corner radius (mm)		Half the thickness							0.50	0.50	0.50	0.50	0.65	0.65	0.65	0.80	0.80	0.80	0.80	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0			
Area to be added for square corners (mm²)		0.054	0.067	0.085	0.108	0.137	0.17	0.21	0.21	0.21	0.21	0.21	0.36	0.36	0.36	0.55	0.55	0.55	0.55	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.9	0.9			

Notes

1. Areas shown below the stepped line in this table are for conductors where the width : thickness ratio is greater than 50 : 1. Such conductors are normally manufactured to the requirements of BS EN 13599.
2. The prefixes R and R" relate to the series of preferred numbers given in BS 2045.

Reference: BS EN 13601.

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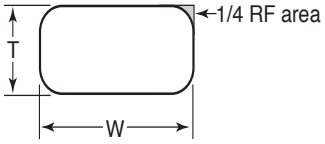
Converting rectangular or square wire area to circular mils

When converting rectangular or square wire to round wire, use the equation below.



Circular mils = [(T x W) - RF] x 1.2732

Where:

T = Wire thickness
W = Wire width
RF = Radius factor

Example: Rectangular wire with dimensions of 0.072" thick by 0.182" wide.

First, determine the rectangular area of the wire by multiplying the wire thickness times its width (in mils).

Area of rectangle = 72 x 182 = 13,104 square mils

Since the corners of the wire are rounded (see drawing above), the rectangular area must be adjusted to obtain the actual square mils. Based on the thickness and width of the wire, determine the standard wire radius from Table 1 (rectangular wire) or Table 2 (square wire). For the rectangular wire example above, the standard wire radius is 0.016". Once the standard wire radius is determined, use Table 3 to find the corresponding radius factor (RF). Calculate the square mils by subtracting the radius factor from the rectangular area of the wire. For a radius of 0.016", the radius factor is 210 square mils.

13,104 - 210 = 12,894 square mils

To convert square mils to circular mils, multiply the square mils by 1.2732:

12,894 x 1.2732 = 16,417 circular mils.

After the circular mils have been calculated, all that remains is to determine, from the available wire stock, what combination of round wires is most suitable.

Notes: To convert circular mils to rectangular mils, multiply the circular mils by 0.7854.

For metric wire area, see 6-18.

TABLE 1: RADIUS OF RECTANGULAR WIRES

THICKNESS, INCHES	RADIUS FOR SPECIFIC WIDTH (INCHES) 0.189 - 0.750	UP TO 0.188 INCL.
0.688 to 0.439 incl.	0.094	—
0.438 to 0.226 incl.	0.063	—
0.225 to 0.166 incl.	0.047	0.047
0.165 to 0.126 incl.	0.031	0.031
0.125 to 0.073 incl.	0.031	0.016
0.072 to 0.051 incl.	Rounded edge	0.016
0.050 and under	Rounded edge	Rounded edge

TABLE 2: RADIUS OF SQUARE WIRES

THICKNESS (INCHES)	RADIUS (INCHES)
0.438 to 0.226 incl.	0.062
0.225 to 0.166 incl.	0.047
0.165 to 0.126 incl.	0.031
0.125 to 0.073 incl.	0.016
0.072 to 0.050 incl.	0.012

TABLE 3: RADIUS FACTOR

RADIUS (INCHES)	RADIUS FACTOR (SQ. MILS)
0.012	124
0.016	210
0.031	838
0.047	1886
0.063	3353
0.094	7544

RECOMMENDED MAXIMUM MAGNET WIRE TENSION FOR COIL MAKING

AWG SIZE	AREA sq. mils	NOMINAL TENSION	
		Max. lbs *	Max. kg *
0	81236	975	442.1
1	64422	773	350.6
1.5	57383	689	312.5
2	51071	613	278.1
2.5	45503	546	247.7
3	40507	486	220.4
3.5	36069	433	196.4
4	32143	386	175.1
4.5	28622	343	155.6
5	25475	306	138.8
5.5	22698	272	123.4
6	20207	242	109.8
6.5	18003	216	98.0
7	16038	192	87.1
7.5	14272	171	77.6
8	12708	152	68.9
8.5	11329	136	61.7
9	10082	121	54.9
9.5	8975	108	49.0
10	7996	96	43.5
10.5	7118	85	38.6
11	6333	76	34.5
11.5	5635	68	30.8
12	5027	60	27.2
12.5	4477	54	24.5
13	3993	48	21.8
13.5	3547	43	19.5
14	3167	38	17.2
14.5	2818	34	15.4
15	2507	30	13.6

AWG SIZE	AREA sq. mils	NOMINAL TENSION	
		Max. lbs *	Max. kg *
15.5	2240	27	12.2
16	1987	24	10.9
16.5	1772	21	9.5
17	1576	19	8.6
17.5	1405	17	7.7
18	1250	15	6.8
18.5	1110	13	5.9
19	989.8	12	5.4
19.5	886.7	11	5.0
20	789.2	9.5	4.3
20.5	702.2	8.4	3.8
21	624.6	7.5	3.4
21.5	555.7	6.7	3.0
22	490.9	5.9	2.7
22.5	441.2	5.3	2.4
23	394.1	4.7	2.1
23.5	349.7	4.2	1.9
24	311.0	3.7	1.7
24.5	277.6	3.3	1.5
25	246.1	3.0	1.4
25.5	219.0	2.6	1.2
26	193.6	2.3	1.04
26.5	174.4	2.1	0.95
27	156.1	1.9	0.86
27.5	138.9	1.7	0.77
28	122.7	1.5	0.68
28.5	109.4	1.3	0.59
29	98.52	1.2	0.54
29.5	86.59	1.0	0.45
30	76.98	0.9	0.41

*Maximum recommended winding tensions are based on 12,000 psi (82,700 kPa) for copper.

Note: Start-up acceleration surge can produce tensions well in excess of running tensions and need to be considered.

This table is offered as a guide to establish effective winding tensions. Use the minimum winding tension that produces a good winding. The type of winding, payoff device, and coil will affect the tension used. Minor variations in the softness of the wire from one lot to another may also dictate minor adjustments.

Reference: Based on information from *Magnet Wire/Winding Wire Engineering Data Handbook*, 12/2009 Rev. 1, Essex Group, Inc., Fort Wayne, IN.

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Magnet wire tensioning and stretch test procedures

TENSIONING

Set the tensioning device to the optimal or desired setting based on experience or appropriate reference(s); see "Maximum Magnet Wire Tension for Coil Making" on Page 6-20. The tension should be adequate to pull the conductor straight along the sides of the pole/form without stretching the wire or otherwise damaging the wire insulation or ground insulation.

STRETCH TEST

Check for wire stretch before starting and during the winding process, and at least once per shift using following procedure.

- Route a test specimen of wire from the spool to the pole/form on the winding machine, using minimum tension to ensure no stretching occurs.
- Mark a length of the test specimen with tape, black marker or other appropriate non-conductive material, starting at the spool or tension device and extending to about midway between the spool and the form.
- When using a reverse-bend device, the marked length of the test specimen may span nearly the entire space between the spool and the device, as long as it does not exceed the distance between the reverse-bend device and the pole/form.

TABLE 1: EXAMPLES OF ACTUAL WIRE STRETCH TEST VALUES*

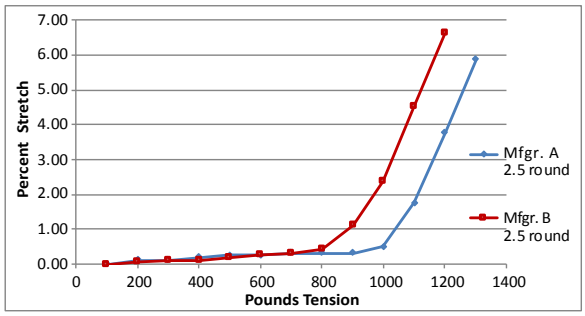
Tension lbs (kg)	Mfgr. A 2.5 AWG round			Mfgr. B 2.5 AWG round		
	in	mm	% stretch	in	mm	% stretch
100 (45.36)	0.00	0.00	0.00	0.00	0.00	0.00
200 (90.72)	0.06	1.52	0.12	0.03	0.76	0.06
300 (136.07)	0.06	1.52	0.12	0.06	1.52	0.12
400 (181.44)	0.09	2.29	0.19	0.06	1.52	0.12
500 (226.80)	0.13	3.30	0.25	0.09	2.29	0.19
600 (272.16)	0.13	3.30	0.25	0.13	3.30	0.25
700 (317.51)	0.16	4.06	0.31	0.16	4.06	0.31
800 (362.87)	0.16	4.06	0.31	0.22	5.59	0.44
900 (408.23)	0.16	4.06	0.31	0.56	14.22	1.12
1000 (453.59)	0.25	6.35	0.50	1.19	30.23	2.37
1100 (498.95)	0.88	22.35	1.75	2.25	57.15	4.50
1200 (544.31)	1.88	47.75	3.75	3.31	84.07	6.62
1300 (589.67)	2.94	74.68	5.87	-------	-------	-------

* Stretch test conducted by L&S Electric, Inc. on 12/8/2016 on 2.5 AWG round wire, 50" test length. Tension measured with 30,000 lb calibrated Hydroscale with 25 lb divisions on scale face.

Note: Besides standard adjustment devices, factors that can affect wire tension include:

- Changes in the friction of tension-brake devices.
- Tensioned wire spools. These will increase wire tension with no change in the spool torque setting as the spool diameter decreases during de-reeling.
- Reverse-bend devices. These can increase wire tension significantly, especially with larger wires. (When not using a reverse-bend machine, de-reel wire from the bottom of the spool to take advantage of the natural reverse bend in the spooled wire.)

Figure 1



Stretch test of 2.5 AWG round magnet wire.

- Measure and record the length of test specimen.
- Set the tensioning device to the optimal or desired setting based on experience or appropriate reference(s).
- Begin winding the wire onto the pole/form, stopping before the first marker reaches the pole/form.
- Measure and record the distance between the marks and compare it with the length recorded initially. If the difference in measured length exceeds 0.25% of the initial length, the wire may be stretching.

  Example: Initial marked length = 50" (1,270 mm)
  Test-tensioned length = 50.125" (1,273.175 mm)

  Stretch = 50.125" (1,273.175 mm)
  - 50.000" (1,270 mm)
  0.125" (3.175 mm) difference

  $$\frac{0.125\text{" (3.175 mm)}}{50\text{" (1,270 mm)}} = 0.0025$$

  0.0025 x 100 = 0.25% stretch

  This is equal to but does not exceed the 0.25% stretch limit, so the wire passes the stretch test.
- Interpretation of test results requires judgement because a tape measure cannot accurately measure down to a 0.001" (0.0254 mm). In the above example, 0.125" (3.175 mm) represents a difference of 1/8" over 50" (1,270 mm), so it probably is within ± 1/32" (0.794 mm). The actual test values given in Table 1 and illustrated in Figure 1 provide examples of some minimal apparent stretching before the wire yields. The appearance of minimal stretching, however, may be due to the wire straightening out as tension is increased and minimal elasticity.
- Record the measurements, calculations, pertinent observations and conditions, including wire size, diameter of spool at time of test, tension device setting, and so forth on the job card, appropriate form, or job-specific note sheet.

(Procedures and test data courtesy of L&S Electric, Inc., Schofield, WI.)

6.2 LEAD WIRE

LEAD WIRE CHART

SUGGESTED AMPACITY VALUES FOR LEAD WIRES

	Size	LEAD WIRE TEMPERATURE RATING				
		90ºC	105ºC	125ºC	150ºC	200ºC
AWG	22	6	7	8	9	10
	20	8	9	10	13	15
	18	14	15	16	17	20
	16	18	19	20	22	25
	14	25	29	31	34	36
	12	30	36	39	43	45
	10	40	46	50	55	60
	8	55	64	69	76	83
	6	75	81	87	96	110
	4	95	109	118	120	125
	3	110	129	139	143	152
	2	130	143	154	160	171
	1	150	168	181	186	197
	1/0	170	193	208	215	229
	2/0	195	229	247	251	260
	3/0	225	263	284	288	297
	4/0	260	301	325	332	346
kcmil	250	290	331	357	386	418
	300	320	365	394	426	461
	350	350	399	431	466	504
	400	380	433	467	505	547
	500	430	490	529	572	619
	600	475	542	584	632	684
	700	520	593	640	692	749
	750	535	610	658	712	770
	800	555	633	683	738	799
	900	585	667	720	778	842
	1000	615	701	756	818	886
Metric (mm^2)	0.50	8	9	10	12	13
	0.75	11	12	14	18	21
	1.0	14	15	16	17	20
	1.5	18	19	20	22	25
	2.5	27	32	34	37	39
	4.0	30	37	40	44	46
	6.0	44	50	55	60	66
	10	56	66	71	78	85
	16	90	97	105	116	132
	25	103	118	128	130	136
	35	135	159	171	176	187
	50	165	182	196	204	218
	70	202	227	244	251	266
	95	251	285	308	318	339
	120	276	324	349	355	368
	150	320	374	404	410	422
	185	365	423	456	466	486
	240	407	464	501	542	587
	300	469	534	577	623	675
	400	553	630	680	735	796
	500	607	692	746	807	874
	625	656	748	807	873	945
	800	721	822	887	959	1038
	1000	740	844	910	984	1066

Note: Lead wire sizes for ampere ratings in these tables represent recommended minimums. It is best to use the lead wire size originally specified by the motor manufacturer. (Reference: Belden Wire and Cable Company.)

MINIMUM ACCEPTABLE LEAD WIRE TEMPERATURE RATINGS

Class B (130°C System)	90°C (194°F)
Class F (155°C System)	125°C (257°F)
Class H (180°C System)	150°C (302°F)
Class R (220°C System)	200°C (392°F)

Note: The thermal class rating for an electrical insulation system need not include the lead wire as a primary component. Rather, the lead wire may be considered a secondary component of the system, and hence may have a lower temperature rating as a component than the rating of the insulation system. (Reference: Belden Wire and Cable Company.)

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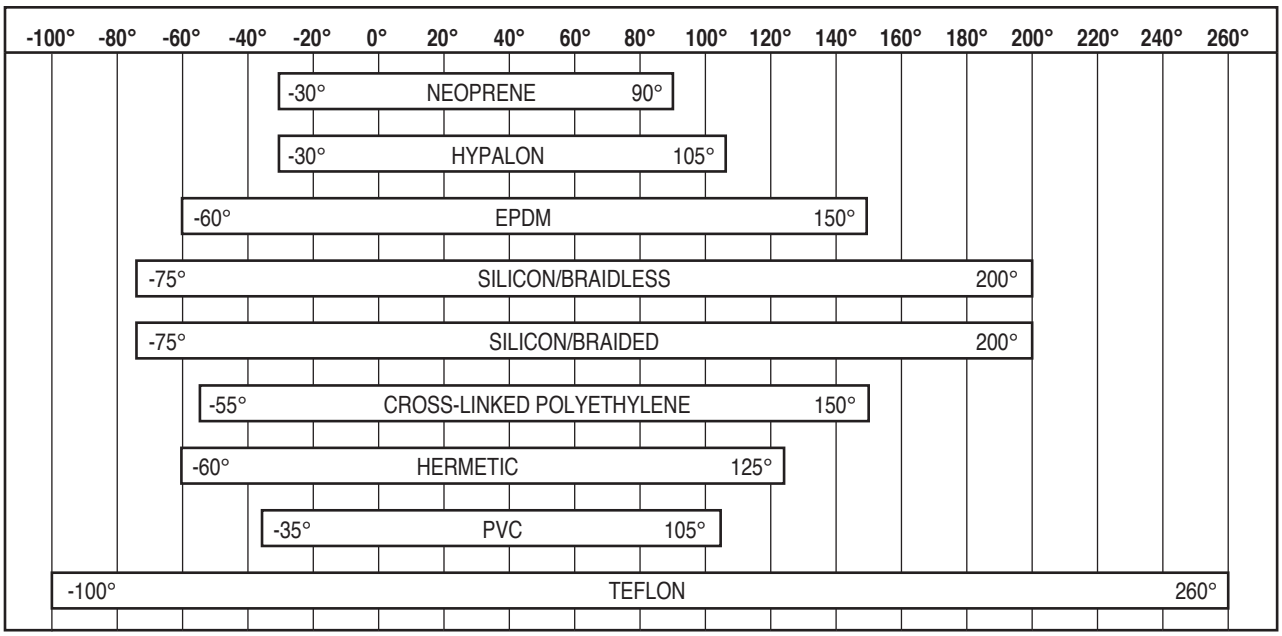
LEAD WIRE CHART—CONTINUED

LEAD WIRE INSULATION CHARACTERISTICS

INSULATION	TEMPERATURE RATING (°C)	U.L. VOLTAGE RATING (VOLTS)	OIL RESISTANCE	OZONE RESISTANCE	ABRASION	FLAME RESISTANCE
Neoprene	90	300/600	Good	Good	Good	Good
PVC	80 105	300 600	Good - Excellent	Good - Excellent	Good	Excellent
Hypalon	105	300/600	Good	Excellent	Good	Good
Cross-linked polyethylene	105 125 150	300 600 600	Good	Good	Excellent	Fair - Good
Hermetic	125	600	Excellent	Good	Good	Poor
EPDM	125 150	600 600	Poor - Fair	Good	Good	Fair
Silicon rubber	150 200	300 600	Fair	Excellent	Poor	Good
Silicone rubber glass braid	150 200	600 600	Fair	Excellent	Excellent	Good
Teflon	150 200	300 300	Excellent	Excellent	Excellent	Excellent

Reference: Belden Wire and Cable Company

LEAD WIRE NOMINAL TEMPERATURE OPERATING RANGES (°C)



Reference: Belden Wire and Cable Company

6.3 TEMPERATURE CLASSIFICATION OF INSULATION SYSTEMS

TEMPERATURE CLASSIFICATION OF INSULATION SYSTEMS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT

INSULATION SYSTEMS*		TEMPERATURE CLASSIFICATION	
Class A	Class 105	105°C	221°F
Class E**	Class 120	120°C	248°F
Class B	Class 130	130°C	266°F
Class F	Class 155	155°C	311°F
Class H	Class 180	180°C	356°F
Class N	Class 200	200°C	392°F

* IEEE Std. 117.

** Used in European equipment.

The numerical value relates to the temperature classification of the insulation system.

The temperature classification indicates the maximum (hot-spot) temperature at which the insulation system can be operated for normal expected service life. Insulation life varies inversely with operating temperature. Materials used in a given insulation system may be rated for temperatures less than, equal to, or exceeding, the temperature classification of the system. See 6.4.

6.4 UL 1446 SYSTEMS OF INSULATING MATERIALS

By Thomas H. Bishop, P.E.,
EASA Senior Technical Support Specialist

Broadly speaking, UL Std. 1446 covers test procedures for evaluating electrical insulation systems for thermal ratings of 120°C and higher, and for voltages of 600 volts or less. Complete descriptions of these systems can be voluminous. A single system, for example, may list over 100 tapes, and full descriptions of the systems could fill a large number of pages.

Varnish and resin manufacturers have had many (but not all) of their products tested according to UL Std. 1446. They also have identified numerous other components that make up compatible, UL 1446-listed systems. The key components of such systems are:

- Varnishes
- Magnet wire
- Ground and interwinding (sheet) insulation
- Minor sheet insulation
- Tapes
- Sleeving
- Wedges, spacers, blocks or panels
- Core tube or bobbin material
- Tie cord
- Potting compound
- Lead wire

To determine if your service center winding system materials match a 155°C or 180°C rating, you must verify that all of the components are in a particular varnish manufacturer's file. A word of caution: Although your materials may match a specific system, always check with the varnish manufacturer before making any statements about their winding systems. UL 1446 systems are just a part of what is termed "component recognition." Therefore, you cannot state that a system is a particular temperature rating based simply on material matching. UL must test the motor as a complete "system" to designate it as such. The UL insulation system files database address is: https://iq.ul.com/systems. Examples: Elantas PD George E87039, John C Dolph E317429, and Von Roll USA E63933.

Note: This artcle was originally published as *EASA Tech Note 24* (December 1998). It was revised in October 2020.

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6.5 AMPACITIES OF BUS BARS

The tables on the following pages should be used as a guide only, as the ampacity of conductors can be greatly affected by factors such as material, ambient conditions, surface emissivity, geometric shape, orientation, proximity effect, skin effect, joint construction, enclosure size and type, phase conductor spacing, the number of conductors in parallel per phase and the harmonic content of the AC waveform.

In addition to the physical and environmental factors, international standards also provide guidance regarding the current limitations of busbars. Some are:

- ANSI/IEEE Std. C37.20.1: *Standard for Metal-enclosed Low-voltage Power Circuit-breaker Switchgear.*
- ANSI/IEEE Std. C37.20.2: *Standard for Metal-clad and Station-type Cubicle Switchgear.*
- IEEE Std. C37.23: *Standard For Metal-enclosed Bus.*
- IEC Std. 62271-1: *High-Voltage Switchgear and Controlgear–Part 1: Common Specifications.*
- IEC Std. 62271-100: *High-Voltage Switchgear and Controlgear–Part 100: Alternating Current Circuit-breakers.*
- IEC Std. 62271-110: *High-Voltage Switchgear and Controlgear–Part 1: Inductive Load Switching.*
- IEC Std. 62271-200: *AC Metal-enclosed Switchgear and Controlgear for Rated Voltages Above 1 kV and up to and Including 52 kV*.
- IEC TR 60943: *Guidance Concerning the Permissible Temperature Rise for Parts of Electrical Equipment, in Particular Terminals* (March 2009).

All the above standards apply to copper bus. The ANSI/IEEE standards recommend a 30°C (54°F) rise and the 65°C (117°F) rise for unplated and silver- or tin-plated (or equivalent) bus respectively. In general, the IEC standards are not as conservative and allow 50° and 75°C (90° and 135°F) rise for bare and silver-plated bus respectively. In the IEC standards, tin-plated bus is assigned a 65°C (117°F) rise. In all cases the maximum ambient temperature is assumed to be 40°C (104°F). In addition, the maximum bus temperature must not exceed the temperature rating of any insulating materials with which the bus may be in contact.

Because allowable temperature rises vary in the standards, depending on the equipment for which they were developed, they should be applied with caution. This is particularly the case when using the information for a non-standard application. For this reason, it is recommended that the design of a bus system for switchgear or motor terminal boxes should be done by or on consultation with qualified technical specialists. In this way pitfalls can be avoided that can lead to high temperature operation and potential damage to components connected to the bus.

Note: The Tables in Section 6.5 apply to single conductors on edge in a horizontal run in air.

REFERENCES

- Copper Development Association, *Publication 22*, January 2001.
- The Aluminum Association, *Aluminum Electrical Conductor Handbook*, 1989.

C110 COPPER ALLOY BUS AMPACITIES—INCHES

SINGLE CONDUCTORS ON EDGE IN A HORIZONTAL RUN IN AIR

DIMENSION (IN)	AREA (IN²)	WEIGHT (LB/FT)	RESISTANCE AT 20°C MICROHMS PER FT	30°C RISE 60 HZ AMPACITY	50°C RISE 60 HZ AMPACITY	65°C RISE 60 HZ AMPACITY
1/16 x 1/2	0.0312	0.121	254	103	136	157
1/16 x 3/4	0.0469	0.181	175	145	193	225
1/16 x 1	0.0625	0.241	132	187	250	285
1/16 x 1½	0.0938	0.362	87.7	270	355	410
1/16 x 2	0.125	0.483	65.8	345	460	530
1/8 x 1/2	0.0625	0.241	132	153	205	235
1/8 x 3/4	0.0938	0.362	87.7	215	285	325
1/8 x 1	0.125	0.483	65.8	270	360	415
1/8 x 1½	0.188	0.726	43.8	385	510	590
1/8 x 2	0.25	0.966	32.9	495	660	760
1/8 x 2½	0.312	1.21	26.4	600	800	920
1/8 x 3	0.375	1.45	21.9	710	940	1100
1/8 x 3½	0.438	1.69	18.8	810	1100	1250
1/8 x 4	0.5	1.93	16.5	910	1200	1400
3/16 x 1/2	0.0938	0.362	87.7	195	260	300
3/16 x 3/4	0.141	0.545	58.4	270	360	415
3/16 x 1	0.188	0.726	43.8	340	455	520
3.16 x 1½	0.281	1.09	29.3	480	630	730
3/16 x 2	0.375	1.45	21.9	610	810	940
3/16 x 2½	0.469	1.81	17.5	740	980	1150
3/16 x 3	0.562	2.17	14.6	870	1150	1350
3/16 x 3½	0.656	2.53	12.5	990	1300	1500
3/16 x 4	0.75	2.9	11	1100	1450	1700
1/4 x 1/2	0.125	0.483	65.8	240	315	360
1/4 x 3/4	0.188	0.726	43.8	320	425	490
1/4 x 1	0.25	0.966	32.9	400	530	620
1/4 x 1½	0.375	1.45	21.9	560	740	860
1/4 x 2	0.5	1.93	16.5	710	940	1100
1/4 x 2½	0.625	2.41	13.2	850	1150	1300
1/4 x 3	0.75	2.9	11	990	1300	1550
1/4 x 3½	0.875	3.38	9.4	1150	1500	1750
1/4 x 4	1	3.86	8.23	1250	1700	1950
1/4 x 5	1.25	4.83	6.58	1500	2000	2350
1/4 x 6	1.5	5.8	5.49	1750	2350	2700
1/4 x 8	2	7.73	4.11	2250	3000	3450
1/4 x 10	2.5	9.66	3.29	2700	3600	4200
1/4 x 12	3	11.6	2.74	3150	4200	4900
3/8 x 3/4	0.281	1.09	29.3	415	550	630
3/8 x 1	0.375	1.45	21.9	510	680	790
3/8 x 1½	0.562	2.17	14.6	710	940	1100
3/8 x 2	0.75	2.9	11	880	1150	1350
3/8 x 2½	0.938	3.62	8.77	1050	1400	1600
3/8 x 3	1.12	4.35	7.35	1200	1600	1850
3/8 x 3½	1.31	5.06	6.28	1350	1800	2100
3/8 x 4	1.5	5.8	5.49	1500	2000	2350
3/8 x 5	1.88	7.26	4.38	1800	2400	2800
3/8 x 6	2.25	8.69	3.66	2100	2800	3250
3/8 x 8	3	11.6	2.74	2650	3550	4100
3/8 x 10	3.75	14.5	2.19	3200	4300	4900

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C110 COPPER ALLOY BUS AMPACITIES—INCHES (Continued)

SINGLE CONDUCTORS ON EDGE IN A HORIZONTAL RUN IN AIR

DIMENSION (IN)	AREA (IN^2)	WEIGHT (LB/FT)	RESISTANCE AT 20°C MICROHMS PER FT	30°C RISE 60 HZ AMPACITY	50°C RISE 60 HZ AMPACITY	65°C RISE 60 HZ AMPACITY
3/8 x 12	4.5	17.4	1.83	3700	5000	5800
1/2 x 1	0.5	1.93	16.5	620	820	940
1/2 x 1½	0.75	2.9	11	830	1100	1250
1/2 x 2	1	3.86	8.23	1000	1350	1550
1/2 x 2½	1.25	4.83	6.58	1200	1600	1850
1/2 x 3	1.5	5.8	5.49	1400	1850	2150
1/2 x 3½	1.75	6.76	4.7	1550	2100	2400
1/2 x 4	2	7.73	4.11	1700	2300	2650
1/2 x 5	2.5	9.66	3.29	2050	2750	3150
1/2 x 6	3	11.6	2.74	2400	3150	3650
1/2 x 8	4	15.5	2.06	3000	4000	4600
1/2 x 10	5	19.3	1.65	3600	4800	5500
1/2 x 12	6	23.2	1.37	4200	5600	6400
3/4 x 4	3	11.6	2.74	2050	2750	3150
3/4 x 5	3.75	14.5	2.19	2400	3250	3750
3/4 x 6	4.5	17.4	1.83	2800	3750	4300
3/4 x 8	6	23.2	1.37	3500	4700	5400
3/4 x 10	7.5	29	1.1	4200	5600	6500
3/4 x 12	9	34.8	0.914	4900	6500	7500

* **Caution:** Because allowable temperature rises vary in the standards, depending on the equipment for which they were developed, they should be applied with caution. This is particularly the case when using the information for non-standard applications. For this reason, it is recommended that the design of a bus system for switchgear or motor terminal boxes should be done by or on consultation with qualified technical specialists.

C110 COPPER ALLOY BUS AMPACITIES—METRIC

SINGLE CONDUCTORS ON EDGE IN A HORIZONTAL RUN IN AIR

DIMENSION (MM)	AREA (MM)	WEIGHT (KG/M)	RESISTANCE AT 20°C MICROHMS PER M	30°C RISE 60 HZ AMPACITY	50°C RISE 60 HZ AMPACITY	65°C RISE 60 HZ AMPACITY	75°C RISE 60 HZ AMPACITY
1.6 x 10	16.0	0.143	1077	85	115	129	139
1.6 x 12	20.0	0.179	862	100	135	152	163
1.6 x 16	25.6	0.229	673	125	170	190	204
1.6 x 20	32.0	0.286	538	150	205	228	245
1.6 x 25	40.0	0.357	431	185	250	281	302
1.6 x 30	48.0	0.429	359	210	290	319	343
2.0 x 10	20.0	0.179	862	95	130	144	155
2.0 x 12.5	25.0	0.223	689	115	155	175	188
2.0 x 16	32.0	0.286	538	140	190	212	229
2.0 x 20	40.0	0.357	431	170	230	258	277
2.0 x 25	50.0	0.446	344	205	280	311	335
2.0 x 30	60.0	0.536	287	240	330	364	392
2.0 x 40	80.0	0.714	215	310	420	471	506
2.5 x 10	25.0	0.223	689	105	145	159	171
2.5 x 12.5	31.25	0.279	557	130	175	197	212
2.5 x 16	40.0	0.357	431	155	215	235	253
2.5 x 20	50.0	0.446	344	190	260	288	310
2.5 x 25	62.5	0.558	275	230	315	349	375
2.5 x 30	75.0	0.671	220	270	370	410	441
2.5 x 40	100.0	0.893	172	350	475	531	571
2.5 x 50	125.0	1.115	137	420	575	637	686
2.5 x 60	150.0	1.339	114	495	675	751	808
2.75 x 10	31.5	0.261	547	125	170	190	204
2.75 x 12.5	30.4	0.352	437	145	200	220	237
2.75 x 16	50.4	0.451	342	180	245	273	294
3.0 x 20	60.0	0.53	287	210	290	319	343
3.0 x 25	75.0	0.67	229	255	350	387	416
3.0 x 30	90.0	0.803	191	295	405	448	482
3.0 x 40	120.0	1.071	143	380	520	577	620
3.0 x 50	150.0	1.339	114	465	635	706	759
3.0 x 60	180.0	1.607	95.7	540	740	820	881
3.0 x 80	240.0	2.142	71.8	700	955	1062	1143
4.0 x 10	40.0	0.357	431	145	195	220	237
4.0 12.5	50.0	0.446	344	170	230	258	277
4.0 x 16	64.0	0.571	269	210	285	319	343
4.0 x 20	80.0	0.714	215	250	340	379	408
4.0 x 25	100.0	0.893	172	300	410	455	490
4.0 x 30	120.0	1.071	143	350	475	531	571
4.0 x 40	160.0	1.428	107	445	605	675	726
4.0 x 50	200.0	1.785	86.2	540	735	820	881
4.0 x 60	240.0	2.142	71.8	625	855	949	1020
4.0 x 80	320.0	2.856	53.8	810	1105	1229	1322
4.0 x 100	400.0	3.571	43.1	980	1340	1487	1600
5.0 x 10	50.0	0.446	344	165	225	250	269
5.0 x 12.5	62.5	0.558	275	195	265	296	318

* **Caution:** Because allowable temperature rises vary in the standards, depending on the equipment for which they were developed, they should be applied with caution. This is particularly the case when using the information for non-standard applications. For this reason, it is recommended that the design of a bus system for switchgear or motor terminal boxes should be done by or on consultation with qualified technical specialists.

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C110 COPPER ALLOY BUS AMPACITIES—METRIC (Continued)

SINGLE CONDUCTORS ON EDGE IN A HORIZONTAL RUN IN AIR

DIMENSION (MM)	AREA (MM)	WEIGHT (KG/M)	RESISTANCE AT 20°C MICROHMS PER M	30°C RISE 60 HZ AMPACITY	50°C RISE 60 HZ AMPACITY	65°C RISE 60 HZ AMPACITY	75°C RISE 60 HZ AMPACITY
5.0 x 16	80.0	0.714	215	240	325	364	392
5.0 x 20	100.0	0.893	172	280	385	425	457
5.0 x 25	125.0	1.116	137	340	465	516	555
5.0 x 30	150.0	1.339	114	395	540	600	645
5.0 x 40	200.0	1.785	86.2	500	680	759	816
5.0 x 50	250.0	2.232	68.9	600	820	911	979
5.0 x 60	300.0	2.678	57.4	705	960	1070	1151
5.0 x 80	400.0	3.571	43.1	915	1250	1389	1494
5.0 x 100	500.0	4.464	34.4	1115	1520	1692	1820
6.3 x 10	63.0	0.562	273	190	260	288	310
6.3 x 12.5	78.8	0.703	218	225	305	341	367
6.3 x 16	100.8	0.899	171	270	370	410	441
6.0 x 20	120.0	1.071	143	315	430	478	514
6.0 x 25	150.0	1.339	114	375	515	569	612
6.0. x 30	180.0	1.607	95.7	435	595	660	710
6.0 x 40	240.0	2.142	71.8	555	755	842	906
6.0 x 50	300.0	2.678	57.4	665	910	1009	1086
6.0 x 60	360.0	3.214	47.8	780	1065	1184	1273
6.0 x 80	480.0	4.285	35.9	990	1355	1503	1616
6.0 x 100	600.0	5.356	28.7	1225	1670	1859	2000
6.0 x 120	720.0	6.428	23.9	1400	1915	2125	2285
6.0 x 160	960.0	8.57	17.9	1755	2400	2664	2865
8.0 x 20	160.0	1.428	107	375	510	569	612
8.0 x 25	200.0	1.785	86.2	445	605	675	726
8.0 x 30	240.0	2.142	71.8	515	700	782	841
8.0 x 40	320.0	2.856	53.8	650	885	987	1061
8.0 x 50	400.0	3.571	43.1	775	1055	1176	1265
8.0 x 60	480.0	4.285	35.9	905	1235	1374	1477
8.0 x 80	640.0	5.713	26.9	1155	1580	1753	1885
8.0 x 100	800.0	7.142	21.5	1320	1800	2003	2155
8.0 x 120	960.0	8.571	17.9	1455	1985	2208	2375
8.0 x 160	1280.0	11.43	13.4	1840	2510	2793	3003
8.0 x 200	1600.0	14.27	10.8	2275	3110	3453	3714
10 x 20	200.0	1.785	86.2	390	535	592	637
10.x 25	250.0	2.232	68.9	470	645	713	767
10 x 30	300.0	2.678	57.4	580	795	880	947
10 x 40	400.0	3.571	43.1	730	995	1108	1192
10 x 50	500.0	4.464	34.4	880	1200	1336	1436
10 x 60	600.0	5.356	28.7	990	1355	1503	1616
10 x 80	800.0	7.142	21.5	1270	1735	1928	2073
10 x 100	1000.0	8.928	17.2	1510	2065	2292	2465
10 x 120	1200.0	10.71	14.3	1755	2395	2664	2865
10 x 160	1600.0	14.28	10.7	2225	3040	3377	3632
10 x 200	2000.0	17.84	8.62	2660	3630	4037	4342
10 x 250	2500.0	22.3	6.89	3155	4310	4789	5150

* **Caution:** Because allowable temperature rises vary in the standards, depending on the equipment for which they were developed, they should be applied with caution. This is particularly the case when using the information for non-standard applications. For this reason, it is recommended that the design of a bus system for switchgear or motor terminal boxes should be done by or on consultation with qualified technical specialists.

C110 COPPER ALLOY BUS AMPACITIES—METRIC (Continued)

SINGLE CONDUCTORS ON EDGE IN A HORIZONTAL RUN IN AIR

DIMENSION (MM)	AREA (MM)	WEIGHT (KG/M)	RESISTANCE AT 20°C MICROHMS PER M	30°C RISE 60 HZ AMPACITY	50°C RISE 60 HZ AMPACITY	65°C RISE 60 HZ AMPACITY	75°C RISE 60 HZ AMPACITY
12 x 25	300.0	2.678	57.4	475	650	721	775
12 x 30	360.0	3.214	47.8	560	765	850	914
12 x 40	480.0	4.285	35.9	755	1030	1146	1232
12 x 50	600.0	5.356	28.7	935	1275	1419	1526
12 x 60	720.0	6.428	23.9	1065	1455	1616	1738
12 x 80	960.0	8.57	17.9	1370	1870	2079	2236
12 x 100	1200.0	10.71	14.3	1650	2255	2504	2693
12 x 120	1440.0	12.85	11.9	1935	2640	2937	3159
12 x 160	1920.0	17.14	8.97	2370	3235	3597	3869
12 x 200	2400.0	21.43	7.18	2835	3870	4303	4628
12 x 250	3000.0	26.78	5.74	3405	4650	5168	5558
16 x 25	400.0	3.571	43.1	625	855	949	1020
16 x 30	480.0	4.285	35.9	715	975	1085	1167
16 x 40	640.0	5.713	26.9	895	1220	1358	1461
16 x 50	800.0	7.142	21.5	1060	1450	1609	1730
16 x 60	960.0	8.57	17.9	1235	1685	1874	2016
16 x 80	1280.0	11.43	13.4	1560	2130	2368	2546
16 x 100	1600.0	14.28	10.7	1875	2560	2846	3061
16 x 120	1920.0	17.14	8.97	2190	2990	3324	3575
16 x 160	2560.0	22.85	6.73	2710	3700	4113	4424
16 x 200	3200.0	28.57	5.38	3200	4370	4857	5223
16 x 250	4000.0	35.71	4.31	3845	5250	5836	6276
16 x 300	4800.0	42.84	3.59	4505	6150	6838	7354

* **Caution:** Because allowable temperature rises vary in the standards, depending on the equipment for which they were developed, they should be applied with caution. This is particularly the case when using the information for non-standard applications. For this reason, it is recommended that the design of a bus system for switchgear or motor terminal boxes should be done by or on consultation with qualified technical specialists.

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6101-T61 ALUMINUM ALLOY BUS AMPACITIES—INCHES

SINGLE CONDUCTORS ON EDGE IN A HORIZONTAL RUN IN AIR

DIMENSION (IN)	AREA (IN^2)	WEIGHT (LB/FT)	DC RESISTANCE AT 20°C RISE MICROHMS PER FT	30°C RISE 60 HZ AMPACITY
1/4 x 1	0.25	0.291	54.720	308
1/4 x 1½	0.375	0.437	36.480	429
1/4 x 2	0.5	0.582	27.360	545
1/4 x 3	0.75	0.873	18.240	768
1/4 x 4	1	1.164	13.680	980
1/4 x 5	1.25	1.455	10.944	1184
1/4 x 6	1.5	1.746	9.120	1381
1/4 x 7	1.75	2.037	7.817	1760
3/8 x 2	0.75	0.873	18.240	678
3/8 x 3	1.125	1.310	12.160	941
3/8 x 4	1.5	1.746	9.120	1191
3/8 x 5	1.875	2.183	7.296	1429
3/8 x 6	2.25	2.619	6.080	1657
3/8 x 8	3	3.492	4.560	2098
3/8 x 10	3.75	4.365	3.648	2534
1/2 x 3	1.5	1.746	9.120	1074
1/2 x 4	2	2.328	6.840	1369
1/2 x 5	2.5	2.910	5.472	1634
1/2 x 6	3	3.492	4.560	1892
1/2 x 8	4	4.656	3.420	2393
1/2 x 10	5	5.820	2.736	2880

* **Caution:** Because allowable temperature rises vary in the standards, depending on the equipment for which they were developed, they should be applied with caution. This is particularly the case when using the information for non-standard applications. For this reason, it is recommended that the design of a bus system for switchgear or motor terminal boxes should be done by or on consultation with qualified technical specialists.

6.6 REFERENCED STANDARDS

The following standards are referenced in this section of the *EASA Technical Manual*.

ANSI/IEEE Std. 117-2015 (Revision of IEEE Std 117-1974) - *IEEE Standard Test Procedure for Thermal Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery*. Institute of Electrical and Electronics Engineers, Inc. New York NY, 2015; ANSI approved 2017.

ANSI/IEEE Std C37.13.1-2016 (Revision of IEEE Std C37.13.1-2006 - *IEEE Standard for Definite-Purpose Switching Devices for Use in Metal-Enclosed Low-Voltage (600 V AC and Below) Power Circuit Breaker Switchgear*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2016; ANSI approved 2017.

ANSI/IEEE Std C37.20.2-2015 (Revision of IEEE Std C37.20.2-1999) - *IEEE Standard for Metal-Clad Switchgear*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2015; ANSI approved 2016.

ANSI/IEEE Std. C37.23-2015 (Revision of IEEE Std C37.23-2003) - *IEEE Standard for Metal-Enclosed Bus*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2016; ANSI approved 2016.

ANSI/NEMA Std. MW 1000-2016: *Magnet Wire*. National Electrical Manufacturers Association. Rosslyn, VA, 2016.

ANSI/UL Std. 1446, Ed. 8: *Systems of Insulating Materials–General*. Underwriters Laboratories, LLC. Camas, WA, 2019; ANSI approved 2020.

ASTM B48-00 (2016): *Standard Specification for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors*. ASTM International. West Conshohocken, PA, 2016.

BS 2045-1965: *Preferred Numbers*. British Standards Institution. London, England, 1965. Withdrawn June 2016.

BS EN 13599-2014: *Copper and copper alloys. Copper plate, sheet and strip for electrical purposes.* British Standards Institution. London, England, 2014.

BS EN 13601-2013: *Copper and copper alloys. Copper rod, bar and wire for general electrical purposes.* British Standards Institution. London, England, 2013.

IEC Std. 62271-1-2017: *High-voltage switchgear and controlgear–Part 1: Common specifications*, ed. 2.0. International Electrotechnical Commission. Geneva, Switzerland, 2017.

IEC Std. 62271-100:2008+AMD1:2012+AMD2:2017 CSV Consolidated version: *High-voltage switchgear and controlgear - Part 100: Alternating-current circuit-breakers*, ed. 2.2. International Electrotechnical Commission. Geneva, Switzerland, 2017.

IEC Std. 62271-110:2017: *High-voltage switchgear and controlgear - Part 110: Inductive load switching*, ed. 4.0. International Electrotechnical Commission. Geneva, Switzerland, 2017.

IEC Std. 62271-200-2011: *High-voltage switchgear and controlgear - Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV,* ed. 2.0. International Electrotechnical Commission. Geneva, Switzerland, 2011.

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