

It is a common belief that copper beryllium alloys are more expensive than other copper alloys. Is this statement true? It is true that copper beryllium alloys will have a higher price in terms of dollars per pound. However, copper beryllium alloys may save you money in the term. They possess exceptional combinations of strength, conductivity, formability, and stress relaxation. This means that connectors produced using these alloys will be reliable, high performance connectors. As connectors continue to follow a miniaturization trend, only copper beryllium alloys will be able to provide the required properties. Other alloys will require larger contacts in order to meet the performance requirements of new designs. Larger contacts mean more pounds of metal to buy, and more surface area to plate, compared to copper beryllium. Factor in the added reliability of copper beryllium, and there will be fewer failures, warranty claims, or other quality-related costs, and copper beryllium alloys will often be the most cost-effective solution!

Design Process Example– One Piece Automotive Box Terminal

Contact Theory: An ideal electrical connector is transparent to the current or signal that passes through it. In reality, the electrical resistance of the interface will cause the current to lose some power. In order to ensure performance of the contact, the resistance must not be allowed to increase to the point of functional degradation. The resistance is directly proportional to the hardness of the contact surfaces and inversely proportional to the contact force between the two halves of the interface. The hardness is determined by the plating. The contact force is determined by the geometry of the design and the base material properties. In order to assure the continued proper functioning of the connector, a minimum contact force must be established and maintained over the life of the contact.

Geometry: Figure 1 shows a cutaway view of a simplified box terminal. The electrical contact is established when an inserted male blade deflects the pair of curved cantilever beam inside the female half of the connector. The important dimensions of the cantilever beams are shown in Figure 2. This particular configuration is chosen since design parameters such as stress, contact force, and allowable deflection are easily calculated by the standard curved cantilever beam equations listed at the end of this design example.

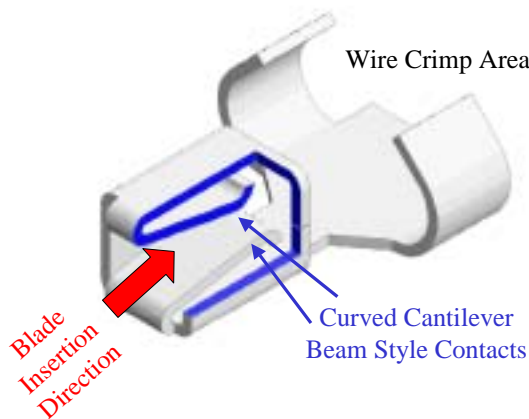


Figure 1. –Box Terminal, Cutaway View

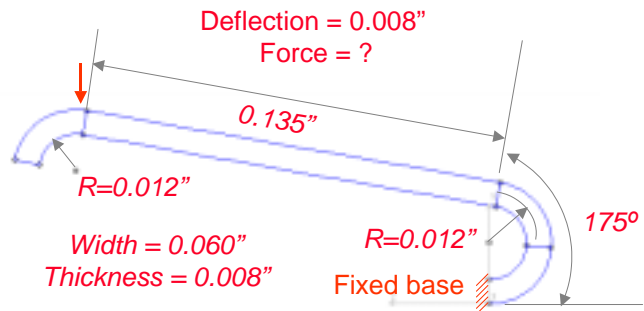


Figure 2. – Curved Cantilever Beam Contact

Design Parameters: Assume an ambient temperature of 150° C for a typical automotive application. The terminal will be coated with tin. This will require a minimum of 100 grams of contact force on each beam. Not only must the beam be designed to provide this contact force upon initial insertion, *it must be designed to maintain this force over the expected life of the connector.*

Base Metal Materials: The spring materials listed in Table 1 are used throughout the world in various automotive connectors. The list includes several types of alloy systems, including a stainless steel. The goal is to find one that meets the design requirements. Some of these alloys are not suitable for box terminals, as will be shown shortly. However, they are included to make the listing as thorough as possible.

Name	UNS #	Type	Name	UNS #	Type	Name	UNS #	Type
190	C17200	Cu Be	Stol 76	C19010	Cu Ni Si	K88	C18080	High Cu
25	C17200	Cu Be	MAX 251C	C64725	Cu Ni Si	MSP1	C18665	High Cu
174	C17410	Cu Be	7025	C70250	Cu Ni Si	NB 109	C19025	High Cu
Brush 60	C17460	Cu Be	7026	C70260	Cu Ni Si	KLF 5	C50715	P Bronze
199	C19900	Cu Ti	425	C42500	Sn Brass	510	C51000	P Bronze
301 SS	S30100	Stainless	688	C68800	Al Brass	654	C65400	Si Bronze

Table 1. – Spring Materials Considered for this Example

Formability: This design has stringent formability requirements. There is a 90° bad way (transverse) bend with an R/t ratio of 1.0, and a 175° good way (longitudinal) bend with a 1.0 R/t ratio. For each of the alloys listed above, select the temper with the highest yield strength that meets the formability requirements. It helps to look at alloys with high yield strengths and good formability. Table 2 below shows the tempers selected, along with the good way and bad way formability for 90° bends.

Name	Temper	GW	BW	Name	Temper	GW	BW	Name	Temper	GW	BW
190	HM	0.5	1.0	Stol 76	R460	0.5	1.0	K88	TM08	0.5	0.5
25	1/2 HT	0.5	1.0	MAX 251C	1/2 H	0.3	0.6	MSP1	1/4 H	0.1	1.0
174	1/2 HT	0.5	0.5	7025	TH03	0.5	0.5	NB 109	H	0.0	1.0
Brush 60	3/4 HT	0.7	0.7	7026	TM02	0.5	1.0	KLF 5	H	0.5	1.0
199	EHP	0.0	1.0	425	1/2 H	0.0	0.0	510	1/2 H	0.0	1.0
301 SS	H	1.0	1.0	688	1/2 H	1.0	1.0	654	1/2 H	1.0	1.0

Table 2. – 90° Bend Formability of the Potential Spring Materials

Yield Strength: The corresponding yield strength for each of the above tempers is shown in Table 3 below. It is desirable to keep the maximum stress in the design around 75% of the yield strength. Higher stress levels will provide higher initial contact forces, but will tend to accelerate stress relaxation over time, and will probably result in lower contact forces at end of life. Lower stress levels will reduce the initial contact force, but will provide no advantage in stress relaxation. A stress level of 75% of the yield strength

provides a margin of safety against overstressing. This will minimize the risk of fewer field failures and warranty claims.

Name	Temper	Strength	Name	Temper	Strength	Name	Temper	Strength
190	HM	123	Stol 76	R460	63	K88	TM08	80
25	1/2 HT	178	MAX 251C	1/2 H	81	MSP1	1/4 H	52
174	1/2 HT	90	7025	TH03	75	NB 109	H	46
Brush 60	3/4 HT	105	7026	TM02	97	KLF 5	H	81
199	EHP	126	425	1/2 H	59	510	1/2 H	58
301 SS	H	140	688	1/2 H	92	654	1/2 H	79

Table 3. – Yield Strength (ksi) of Strongest Temper Suitable for these Bends

Nominal Design Stress: Using standard curved cantilever beam equations, the nominal stress in the design is computed and compared to the maximum stress determined earlier. These results are displayed in Table 4. The stress levels in the seven alloys shown in red exceed the allowable limit, and are thus unsuitable in this particular design.

Alloy Name	Design Stress	Allowable Stress	Alloy Name	Design Stress	Allowable Stress	Alloy Name	Design Stress	Allowable Stress
190	64	92	Stol 76	66	47	K88	69	60
25	64	133	MAX 251C	64	61	MSP1	61	39
174	68	68	7025	64	56	NB 109	64	35
Brush 60	68	79	7026	64	73	KLF 5	59	61
199	62	95	425	59	44	510	54	43
301 SS	95	105	688	57	69	654	57	59

Table 4. – Nominal Design Stress and Maximum Allowable Stress Limit (ksi)

Initial Contact Force: Using the design geometry and the allowable stress, we calculate the initial contact force, shown in Table 5. The design force is derived from the cantilever beam equations. The actual force is equal to the design force in the alloys with a design stress lower than the allowable limit. For the remainder of the alloys (previously eliminated in the last step), the actual force is the defined as the contact force at the maximum allowable stress level.

Alloy Name	Design Force	Actual Force	Alloy Name	Design Force	Actual Force	Alloy Name	Design Force	Actual Force
190	114	114	Stol 76	118	84	K88	122	106
25	114	114	MAX 251C	113	107	MSP1	109	69
174	120	120	7025	114	100	NB 109	113	61
Brush 60	120	120	7026	114	114	KLF 5	105	105
199	110	110	425	105	78	510	96	76
301 SS	168	168	688	102	102	654	102	102

Table 5. – Nominal Design Contact Force and Maximum Achievable Contact Force (grams)

Allowable Deflection: The maximum allowable deflection, shown below in Table 6, is calculated at the maximum allowable stress level. An allowable deflection greater than the nominal will allow for any overstressing due to off-center insertion of the blade.

Alloy Name	Temper	Maximum Deflection	Alloy Name	Temper	Maximum Deflection	Alloy Name	Temper	Maximum Deflection
190	HM	0.011	Stol 76	R460	0.006	K88	TM08	0.007
25	1/2 HT	0.017	MAX 251C	1/2 H	0.008	MSP1	1/4 H	0.005
174	1/2 HT	0.008	7025	TH03	0.007	NB 109	H	0.004
Brush 60	3/4 HT	0.009	7026	TM02	0.009	KLF 5	H	0.008
199	EHP	0.012	425	1/2 H	0.006	510	1/2 H	0.006
301 SS	H	0.009	688	1/2 H	0.010	654	1/2 H	0.008

Table 6. – Maximum Allowable Deflection (inches) of Contacts

Temperature Rise: Assuming that the 15 amp current is split equally between the two cantilever beam contacts, the temperature rise due to the 7.5 amp current in each beam is calculated. The result is doubled and added to the 150° C ambient temperature to get the operating temperature of the contact, as shown in Table 7. The stainless steel alloy now drops out of consideration due to the excessive operating temperature of 528° C.

Alloy Name	Temp Rise	Operating Temp	Alloy Name	Temp Rise	Operating Temp	Alloy Name	Temp Rise	Operating Temp
190	3	156	Stol 76	0.6	152	K88	0.3	151
25	3	156	MAX 251C	1	152	MSP1	0.4	151
174	0.6	151	7025	1	142	NB 109	1	152
Brush 60	0.7	151	7026	1	152	KLF 5	0.6	151
199	14	178	425	2.5	155	510	7	164
301 SS	189	528	688	6	162	654	29	208

Table 7. – Temperature Rise and Operating Temperature (°C)

Stress Relaxation: Once the operating temperature is known, the stress relaxation will be calculated. Stress relaxation data is available for most of these alloys at 1000 hours for temperatures at 100°, 150°, and 200° C. From this data, the stress remaining in a contact made from each of these alloys can be approximated at the operating temperature, as shown below in Table 8.

Alloy Name	Temper	Remaining Stress	Alloy Name	Temper	Remaining Stress	Alloy Name	Temper	Remaining Stress
190	HM	88%	Stol 76	R460	83%	K88	TM08	84%
25	1/2 HT	88%	MAX 251C	1/2 H	87%	MSP1	1/4 H	80%
174	1/2 HT	80%	7025	TH03	82%	NB 109	H	80%
Brush 60	3/4 HT	85%	7026	TM02	70%	KLF 5	H	70%
199	EHP	96%	425	1/2 H	47%	510	1/2 H	80%
301 SS	H	?	688	1/2 H	25%	654	1/2 H	50%

Table 8. – Estimated Remaining Stress over Connector Life

Remaining Contact Force: The contact force remaining for each of the alloys is shown below in Table 9. Only four alloys remain in consideration. The other alloys are not adequate in this application because they will permanently deform, operate at too high a temperature, or fail to retain sufficient contact force. Three of the four copper beryllium alloys make the cut, as does the copper titanium alloy.

Alloy Name	Temper	Remaining Force	Alloy Name	Temper	Remaining Force	Alloy Name	Temper	Remaining Force
190	HM	100	Stol 76	R460	69	K88	TM08	89
25	1/2 HT	100	MAX 251C	1/2 H	94	MSP1	1/4 H	55
174	1/2 HT	95	7025	TH03	82	NB 109	H	49
Brush 60	3/4 HT	102	7026	TM02	80	KLF 5	H	73
199	EHP	106	425	1/2 H	36	510	1/2 H	61
301 SS	H	?	688	1/2 H	25	654	1/2 H	51

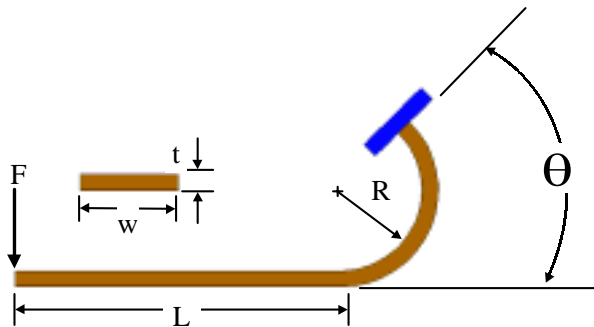
Table 9. – Estimated Remaining Contact Force Connector Life

Alloy Selection: As a final step, a non-linear finite element analysis would verify the suitability of each of these four alloys. Alloys 190, 25, and Brush 60 copper beryllium, and the Alloy 199 copper titanium will all work in this application. Alloy Brush 60 ¾ HT meets all of the minimum requirements, and has the lowest cost. Consequently, **Alloy Brush 60 ¾ HT** would seem to be the optimal material choice for this application.

Curved Cantilever Beam Equations: The analysis used the following calculations for a curved cantilever beam with a rectangular cross section and bend angle between 90 and 180 degrees.

Definitions:

- E = Elastic Modulus (psi)
- J = Current (A)
- γ = Electrical Conductivity (A/V-in)
- κ = Thermal Conductivity (V-A/in-°F)



Stress as a function of deflection:

$$\sigma_{\max} = \frac{E \cdot t \cdot (L + R)}{2 \cdot R^3 \cdot [NDT_1]} \cdot d$$

Contact force as a function of deflection:

$$F = \frac{E \cdot w \cdot t^3}{12 \cdot R^3 \cdot [NDT_1]} \cdot d$$

Maximum deflection as a function of yield strength:

$$d_{\text{yield}} = \frac{2 \cdot R^3 \cdot [NDT_1]}{E \cdot t \cdot (L + R)} \cdot \sigma_{\text{yield}}$$

Temperature Rise:

$$\Delta T = \frac{J^2 L^2}{2\gamma\kappa w^2 t^2}$$

Non-dimensional term used in the above equations:

$$[NDT_1] = \left[\frac{1}{3} \cdot \left(\frac{L}{R}\right)^3 + \left(\frac{L}{R}\right)^2 \cdot \left(\theta \cdot \frac{\pi}{180}\right) + 2 \cdot \left(\frac{L}{R}\right) \cdot (1 - \cos\theta) + \left(\frac{\theta}{2} \cdot \frac{\pi}{180}\right) - \frac{\sin 2\theta}{4} \right]$$